CII FOUNDATION

CII-ITC Centre of Excellence
for Sustainable Development

CII
Confederation of Indian Industry
125 Years - Since 1895

CII
Cleaner Air
Better Life

IMPACTS AND LEARNINGS OF CROP RESIDUE MANAGEMENT PROGRAMME

Authors:
Mohit Sharma | Ishan Sahajpal | Aditya Bhuyan

Published by Confederation of Indian Industry (CII), The Mantosh Sondhi Centre; 23, Institutional Area,
Lodi Road, New Delhi 110003, India,

Tel: +91-11-24629994-7, Fax: +91-11-24626149; Email: info@cii.in; Web: www.cii.in

GOVERNMENT, RESEARCH & TECHNICAL COLLABORATIONS

NITI Aayog

Ministry of Environment, Forest and Climate Change

CII-ITC Centre of Excellence for Sustainable Development

ਪੰਜਾਬ ਪ੍ਰਦੂਸ਼ਣ ਕੰਟਰੋਲ ਬੋਰਡ
Punjab Pollution Control Board

DEPARTMENT OF AGRICULTURE, HARYANA

SUPPORTED BY

birlasoft — CK BIRLA GROUP

Bharat Petroleum — energising lives

CLP India — The power of new standards

Cummins

GAIL

ONGC

PTC Foundation — emPowering Community

PFS

ReNew Power

Royal Enfield

Rau's IAS Study Circle — Since 1953

SIAM — Society of Indian Automobile Manufacturers

The Hi-Tech Gears Ltd.

IMPLEMENTATION

CII FOUNDATION

GBDSGNS © Foundation — Promise to Create a Brighter Tomorrow

DOCTORS FOR YOU — THERE TO CARE

Farmer Producer Organizations

Khushaal Agri Producer Association, Sahabazpura, Ludhiana

Khushaal Seed Producers Association, Jalaldiwal, Ludhiana

Khushaal Honey and Dairy Producers Association, Boparai Khurd, Ludhiana

Farmer Cooperatives Societies

Jaaso Majra Multipurpose Farmer Cooperative Society, Patiala
Mallewal Multipurpose Farmer Cooperative Society, Patiala
Bhorey Multipurpose Farmer Cooperative Society, Patiala
Ghaniwaal Multipurpose Cooperative Society, Patiala
Todderwaal Multipurpose Cooperative Society, Patiala
Dhindrala Dhindsa Multipurpose Cooperative Society, Patiala
Phalia khurd Multipurpose Cooperative Society, Patiala
Gurdittpura Multipurpose Cooperative Society, Patiala
Matourda Multipurpose Cooperative Society, Patiala
Dittupur Jattan Multipurpose Cooperative Society, Patiala
Kansuha Multipurpose Cooperative Society, Patiala
Khanoura Multipurpose Cooperative Society, Patiala
Todarwal Multipurpose Cooperative Society, Patiala
Pedni Multipurpose Cooperative Society, Patiala
Galwatti Multipurpose Cooperative Society, Patiala
Dhingi Multipurpose Cooperative Society, Patiala
Kheri Maniya Multipurpose Cooperative Society, Patiala
Bhidwal Multipurpose Cooperative Society, Patiala
Sadduheri Multipurpose Cooperative Society, Patiala
Bharat Multipurpose Cooperative Society, Rohtak
Thakur Agriculture Society, Fatehabad
Mohammadpuria Agriculture Welfare Society, Sirsa

Contents

EXECUTIVE SUMMARY

CII Crop Residue Management (CRM) Programme covered rice intensive (99% of agricultural area under rice) geographies of Punjab and Haryana in 2019 creating a successful model for large-scale behaviour change among farmers. It is worth noting that penetration of in-situ technologies has improved significantly in two states since the launch of Government of India's Central Sector Scheme in 2018, the same time when CII-NITI Aayog Biomass Management Report recommended upscaling in-situ technologies as actionable and cost-effective solution. But farmers' awareness on cost-benefits of different solutions and penetration of needed farm tools are not yet adequate for tackling air pollution in rice intensive areas. This gap was filled by CII's CRM Programme with scaled up intervention in 102 villages across six districts of North Western States in 2019. Overall, 64% of rice straw produced in newly intervened geographies was being managed through crop residue burning in 2018. This came down to 24% in one year as a result of field interventions in 2019-20. Majority of total intervened farmers (87% of 20855 farmers) practiced improved crop residue management practices in 2019. While overall 84% rice area was covered under improved CRM practices in 2019, four out of six clusters saw 90% rice area being covered under the same. In two districts, change was also led predominantly by ex-situ management in wake of soil conditions not being conducive to in-situ management. Balers were additionally provided to farmers in these districts on sharing-basis. Out of all those farmers who used mulcher (one of the seven most widely used tools for in-situ management), 91% accessed it via shared-economy model created with farmer groups. Overall, the adoption of improved crop residue management practices went up across 102 villages by 83% in one year: 24% increase in area under mulching, 89% increase in area under soil-incorporation and 142% areas under baling (ex-situ).

In parallel to field intervention, data on farming practices is continuously collected from farmers to analyse various factors leading up to adoption of sustainable practices, evaluate solutions and assess impacts of CRM field intervention. Contrary to conventional wisdom, fuel consumption under in-situ management practices (for both methods i.e. mulching and soil incorporation) is found to be 23% lower when compared to crop residue burning. This is owing to multiple tool runs required under conventional extensive tillage regime associated with crop residue burning. Fuel consumption is also a good approximation of fuel cost for farmers and onsite diesel emissions. Total 183 thousand tonne of rice straw was avoided from burning in 2019 resulting into savings of 1.29 thousand tonne PM^{10}, 770 tonne $PM^{2.5}$, 3 thousand tonne gaseous pollutants which are also precursors to fine or ultrafine particles, 0.2 million tonne GHGs and 86 tonne Black Carbon. Also, 158 thousand tonnes of organic matter was added back to the soil. It is established through hard data from farmers that in-situ practices in intervened geographies resulted in 13% water savings. Total savings worth 10.15 billion litres are achieved due to recycling of organic matter back into the soil.

Cost of crop residue management, both in-situ and as ex-situ management, is still a deterrent to their large-scale adoption by farmers. A detailed cost assessment of CRM was developed from farmers data to understand costs of different methods including burning under two different scenarios- intervention group (CII intervened area) and standards group (without any external intervention). Contrary to popular belief that Crop Residue Burning (CRB) does not cost farmer, CRB costs farmers INR 2948 per acre. This is still significantly lesser compared to cost paid by farmers for in-situ management in areas without intervention. In CII intervened areas, farmers paid 10% lesser than the cost of CRB for in-situ management (INR 2630 per acre and INR 2672 per acre for mulching and soil incorporation respectively). Shared-economy model made cost of these operations affordable to all farmers. Cost of in-situ management in areas outside intervention is found to be 7-8% higher compared to burning. Baling (ex-situ) costs farmers 67% more when compared to CRB. Even under the shared economy model or intervention group, ex-situ costs 48% more (INR 4350/acre) compared to CRB. Scaling ex-situ solutions, therefore, requires significant intervention to exploit economy-wide circularities and bridge the gap between in-situ management solutions and air pollution.

Besides immediate upfront cost of crop residue management, productivity of next crop, which is sown immediately after rice, is a major concern for farmers adopting new agricultural practices. This impact assessment study finds that yield under improved crop residue management practices in CII intervened area showed significant improvement compared to burning- (1) 2.93% under mulching (2) 7.32% under soil incorporation (3) 5.37% under baling (ex-situ). These findings also support the data on higher adoption rate for soil incorporation and baling compared to mulching. Demand for chemical inputs are found to be comparable across practices and no clear evidence could be generated for savings under in-situ management practices. But this busts myths among farmers associated with productivity of plots under mulching.

These findings highlight that fundamental shift in farmers behaviour is possible at large scale, if actionable and affordable solutions are made available to them on time. Shared-economy model is crucial for scaling use of farm tools which are needed by farmers from only few hours to few days in a year. Also, ex-situ requires major focus in future and significant intervention is required to make it affordable to farmers. Ex-situ is the only a feasible solution for farmers who cannot utilise rice straw due to specific soil type or crop variety, but it also has crucial role when soil organic carbon reaches saturation and farmer may want to skip application of crop residue to soil. It is an important part of overall biomass management ecosystem owing to its important role in bridging the gap between in-situ management practices and crop residue burning.

1. INTRODUCTION

This study presents the findings of impact assessment undertaken by CII's 'Cleaner Air Better Life' to assess overall impacts and learnings of Crop Residue Management (CRM) Programme in 2019-20 with an objective to scale cost-effective and actionable solutions with farming communities. The CRM programme spanned 102 villages[1] of Punjab and Haryana during the rice harvesting season starting in the month of October 2019. The Intervened rural geographies are predominantly rice or paddy growing areas (99% area under Rice) of North Western States where farmers are in urgent need of proven solutions to crop residue burning. These rural geographies are mapped in Figure 1 with details on number of villages, farmer households and agricultural area intervened in six districts of Punjab and Haryana intervened in 2019.

Total intervened area in these geographies is equivalent to 97,531 acres[2] or 39,469.4 hectares agricultural area covering more than 20,855 farmers. These are rice producing belts of Punjab and Haryana where 99% of this agricultural area is under rice. Second major crop is wheat which is sown on 95% of the agricultural area. 28% of this total agricultural area is found to be sown with other diverse set of crops such as potato, sunflower, carrots, green gram, peas, mustard, sugarcane etc. While rice-wheat is the most predominant crop rotation in region occupying most of the agricultural land, about one fifth of this is consisted of numerous other crop rotations such as are rice-potato-sunflower, rice-peas-wheat, rice-wheat-green gram, maize-wheat-green gram etc.

In 2018, crop residue burning was used to manage 64% of total rice straw generated in these rural geographies without any outside intervention. As a result of field interventions in 2019, overall burning came down to 24% of rice straw produced in these areas. This is achieved through steep increase of 83% in adoption of improved crop residue management or sustainable agricultural practices from 2018 to 2019. In terms of agricultural area and farmers, sustainable agricultural practices were adopted on 87% area by 84% of all farmers, further limiting the conventional method of complete and open burning for managing post-harvest remains of rice to 13% of area and 16% of farmers in 2019.

The impacts of CRM programme are spread across all three dimensions of sustainability (See Figure 2) and are accordingly detailed in subsequent subsections under the Section 4. The environmental impacts of improved CRM practices are wide-ranging and lead to benefits across all sub-system of natural environment. Based on primary data from farmers in 102 intervened villages, these impacts of CRM programme in 2019 are quantified wherever possible in this study while Figure 2 depicts the all possible impacts which can be quantified with longitudinal studies over longer time horizon. Social impacts of CRM programme are understood by capturing change in adoption of improved crop residue management practices and assessing whether field interventions were inclusive to all farmers belonging to different size classes. Assessed environmental impacts include savings in local and regional air pollution, water conservation which is highly relevant for two states, and global climate impacts.

Detailed economic assessment is undertaken to understand the cost of different CRM practices in intervened areas vis-a-vis areas without field intervention. Cost of CRM operations between harvesting rice and sowing of next crop, significantly affects farmer's decision to burn or adopt alternate method for CRM. Not only this, these operations may impact farm productivity in the subsequent crop affecting long-term adoption of new practice with farmers. Productivity of predominant crop after rice, that is wheat, is assessed to understand impact of this programme. Significant improvements in wheat yield are observed, while no clear evidence could be found for savings on farm inputs, except fuel and water. Quantifying all costs and benefits of CRM programme, including long-term soil health benefits which are slowly being realised by farmers, requires more data on farming practices over longer time horizons and is primary focus of future research efforts.

[1]Programme implemented in 105 villages and three more villages were added towards the end but impact assessment study is only being undertaken for 102 villages which were part of the baseline study initiated in September 2019.

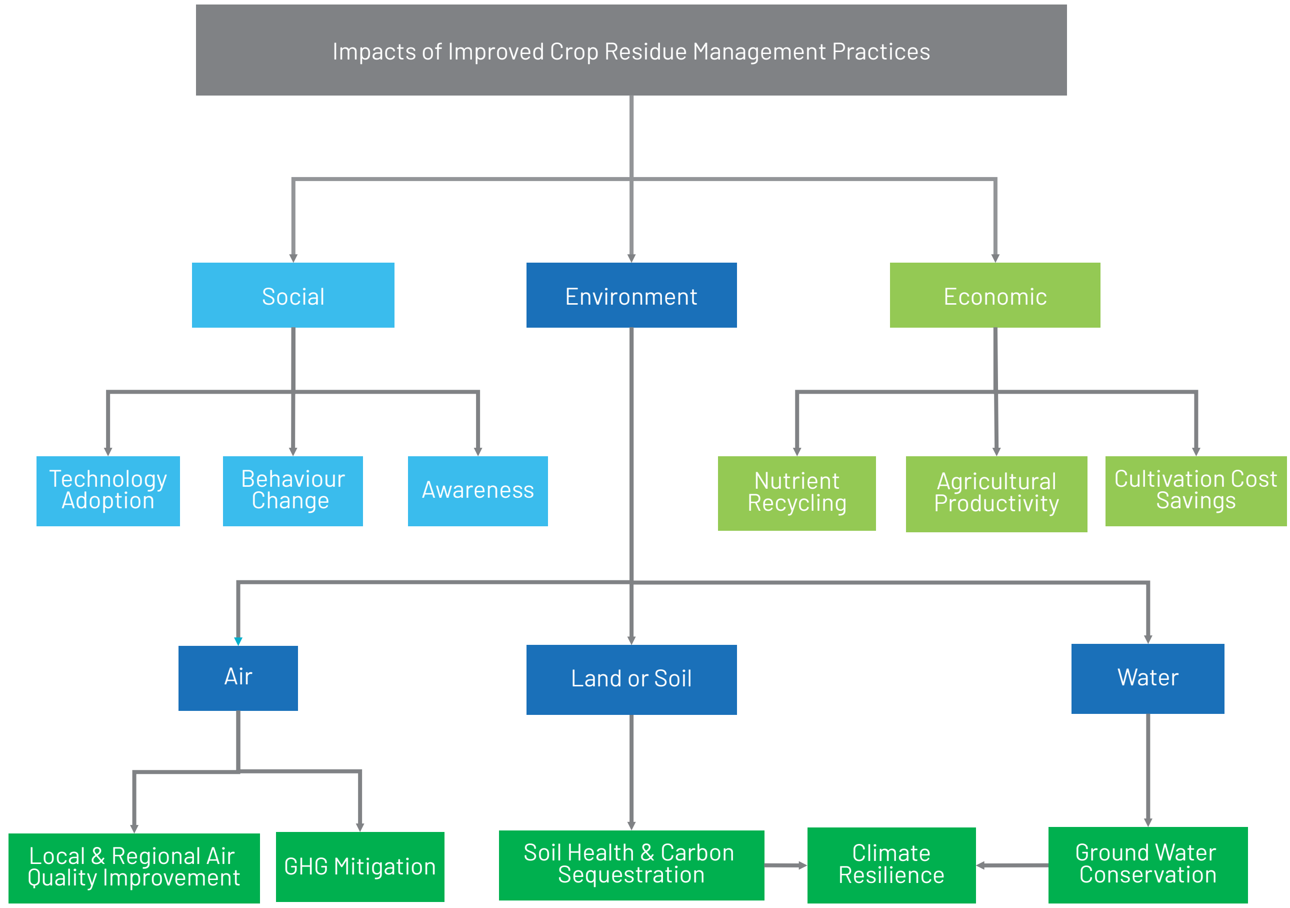
[2]1,03,500 acres in 105 intervened villages

Figure 1. Details of intervened geographies under this study

District	Farming Communities [no. of villages]	Farmer households (HH) [no. of HHs]	Agricultural Area [acre]
Barnala	3	1220	5200
Fatehabad	4	2034	5500
Ludhiana	29	7355	37446
Patiala	56	7103	38285
Rohtak	2	1264	4500
Sirsa	8	1879	6600
Total	**102**	**20855**	**97531**

Source: CII Cleaner Air Better Life (2020) compilation of Land Records Data in 2019

Figure 2. Overview of different impacts of improved crop residue management practices and broad categorisation of these impacts used in this study



Source: CII Cleaner Air Better Life (2020) Analysis

2. BACKGROUND

CII partnered with NITI Aayog for the 'Cleaner Air Better Life' initiative to develop consensus on actionable steps to address scientifically identified sources of air pollution in Delhi National Capital Region (NCR). Four action plans including Biomass Management, Clean Fuel, Clean Industry and Clean Transportation were accordingly prepared by Cleaner Air Better Life by consulting diverse stakeholders across airshed. CII-NITI Aayog Action Plan for Biomass Management was prepared by the Task Force on Biomass Management anchored by the Ministry of Environment Forest and Climate Change (MoEFCC), Government of India (GoI). Actionable steps were identified by task force by consulting Punjab Agriculture university (PAU) and farmers communities. Scaling up in-situ technologies using shared-economy model was proposed as the immediate step by CII-NITI Aayog Action Plan released in February 2018 (CII-NITI 2018). Taking note of actionable in-situ solutions, GoI launched Central Sector Scheme as part of the Union Budget 2018-19 to support farmers in adopting these technologies in affected states of Punjab, Haryana and Western Uttar Pradesh.

In the same year, CII initiated the pilot programme on Crop Residue Management in 19 villages of Ludhiana and Patiala districts (Punjab State) to demonstrate these options at scale. The model was highly successful in demonstrating actionable solutions with farming communities and CII's first impact assessment, released in August 2019, finds that 74% area was made free of burning in 2018 as opposed to 96.5% area under burning in 2017. The programme is scaled to 102 villages[3] of Punjab and Haryana in 2019 and this study presents findings of detailed assessment of these scaled programme interventions in 2019. Crop Residue Burning (CRB) still remain a major challenge for peak air pollution across North West India and It is estimated that emissions would increase by 45% in 2050 if existing practices continue in the same manner (Singh et al 2020).

CRM programme is designed to develop a scalable delivery models for cost-effective solutions to rural communities affected by Crop Residue Burning (CRB). CII field interventions follow an end-to-end approach consisting of following key components-

1. Behaviour change communication: Continuous dialogues are held with farming communities through multiple communication channels to build awareness on air pollution from CRB and its impacts on human health as well as agricultural productivity.

2. Financial support to farming communities: Tools needed by farming communities are procured either at the full cost or subsidised cost under the Central Subsidy Scheme (depending on their availability) to create shared-economy model for farm tools with farmer groups.

3. Capacity building of farmers for improved crop residue management: Farm level demonstrations and trainings were conducted in partnership with State Agriculture Universities (SAUs) and State Departments of Agriculture. Master trainers and village volunteers were trained at SAUs to provide further technical handholding and support to farmers.

4. Participatory monitoring of stubble burning at village level: Communities take charge of their emission by monitoring burning incidents in villages and undertaking immediate remedial measures. Field workers and local NGOs are engaged by CII field coordinators work very closely with local-level Nigrani Committees for monitoring and controlling burning by providing timely solutions.

[3]Newly intervened villages or those intervened for the first time in 2019 are 86 villages from Punjab and Haryana. Remaining 16 villages were part of demonstration programme in 19 villages of Punjab in 2018 and were intervened again in 2019

3. METHODOLOGY

Impacts and key lessons of CII's CRM programme is based on a combination of four key steps as shown in the Figure 3. Custom digital data collection platform was designed to collect the farming data in 102 villages with geo-tagged information. Data was collected by dedicated team of field volunteers trained in digital data collection using mobile application. Extensive door-to-door survey of 1599 farmers or farming households was undertaken by field volunteers to collect data on farming practices with an overall objective to understand adoptions of different crop residue management practices and seek farmers' feedback to improve crop residue management programme. Random and stratified sampling of farmers was undertaken across 102 village to cover-

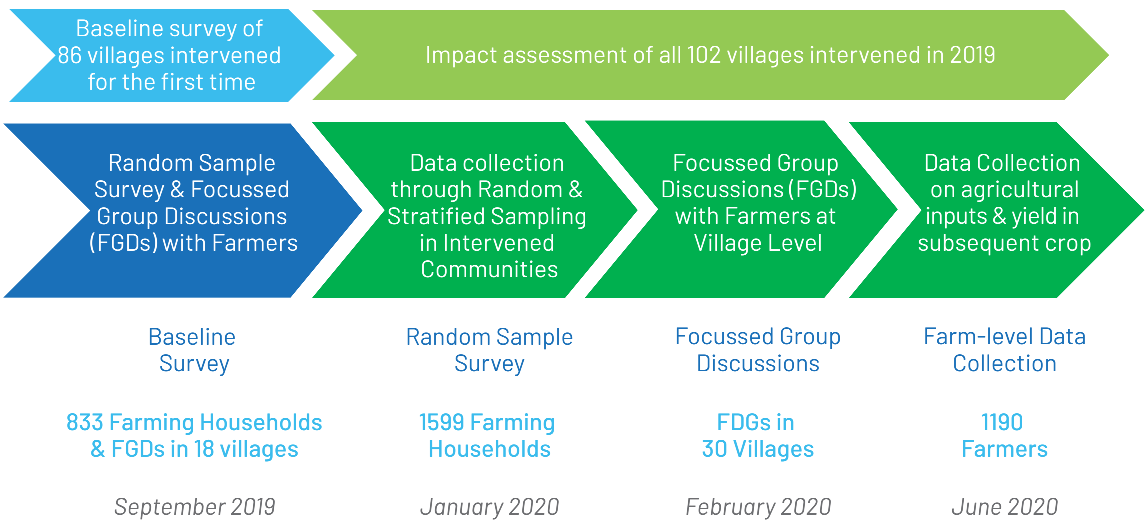
1. Intervened farmers adopting different practices whether convention or alternate.

2. All farmers belonging to different strata or size classes in each village.

Depending on the size of villages, 15-20 samples per village were collected in 102 intervened villages in 2019. Unique community-based approach is followed to cover different communities and socio-economic strata in villages. This means that-

- Field volunteers, with good understanding of rural settings, targeted specific farming communities within villages for balanced inputs. Different communities in single village, which exist organically due religion and caste-based divide, were targeted for inputs which were balanced and as random as possible

Figure 3. Methodology for Assessing Impacts of Crop Residue Management in 102 villages intervened by CII in 2019-20

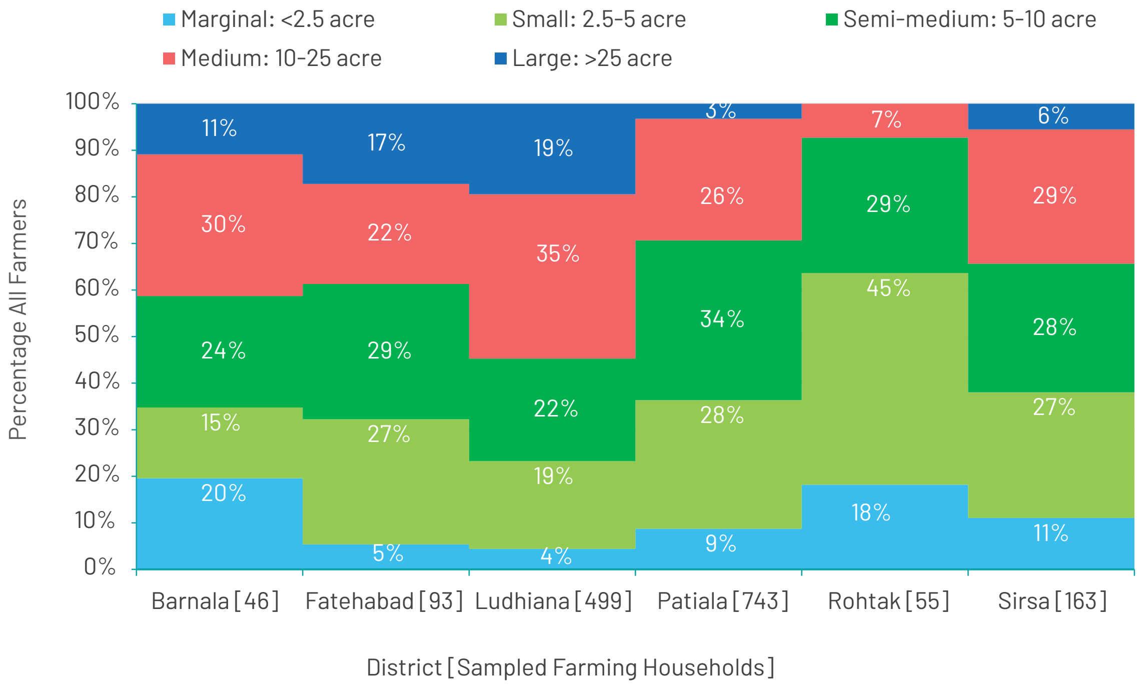


Source: CII Cleaner Air Better Life (2020) Analysis

- Stratification of samples was undertaken to limit number of farmers responding from each stratum (See Figure 4) based on information from the baseline survey. Baseline establishes the extent of crop residue burning and adoption of alternate practices before beginning of the field interventions

Collected datasets were further validated by research team with focussed group discussions with farmers and cross-validations within the collected datasets which are elaborated in relevant sections. Further data on full yearly cropping cycle ending in June 2020 was collected from 74% or 1190 of these surveyed farmers.

Figure 4. Sampled Farmers across 102 villages and coverage of operational land-holdings across Districts



Source: CII Cleaner Air Better Life (2020) Analysis

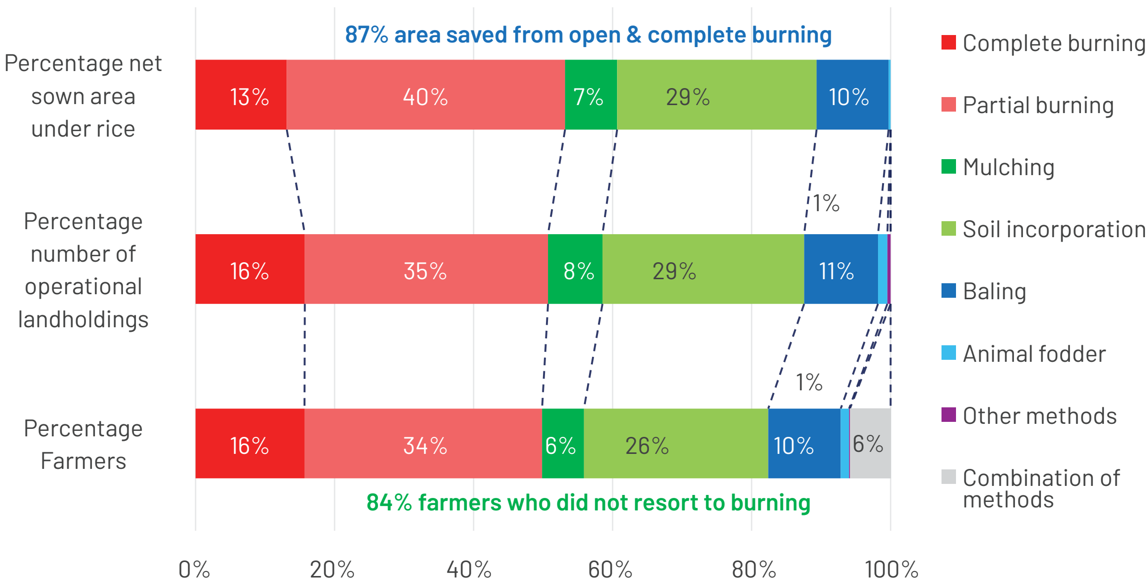
4. IMPACTS

4.1 Social Impacts

In 2019, the CRM programme was implemented across 102 villages in six districts of Punjab and Haryana as shown in Figure 1. Out of total intervened, majority of farmland and farmers (83% and 75% respectively) are located across three districts of Punjab and remaining are located (17% farmland and 25% farmers) across three districts of Haryana.

Analysis of data from 102 villages in Punjab and Haryana indicates that 1599 sampled farmers divided their operational landholdings into total 1709 fields for adoption of various practices. Focussed group discussion with farming communities also indicate that 5-6% farmers divided their operational landholdings into number of 2-3 plots under different practices in order to reduce risks associated with new technologies or agricultural practices. Accordingly, technology adoption across these 1709 such fields under different crop residue management practices is analysed to build the full picture of technology adoption in 2019 (See Figure 5). From analysis of primary data, it is deduced that 84% farmers (out of total 20855 farmers in 102 villages) practiced new methods substituting open and complete burning of rice straw (with ±1.73 % margin of error for 95% confidence level). This is equivalent to 87% of farmland under rice where complete and open burning of rice straw was avoided. While only 16% farmers resorted to open and complete burning of rice straw. There are 32% farmers

Figure 5. Adoption of practices across 102 villages by farmers, operational landholdings and agricultural area under rice



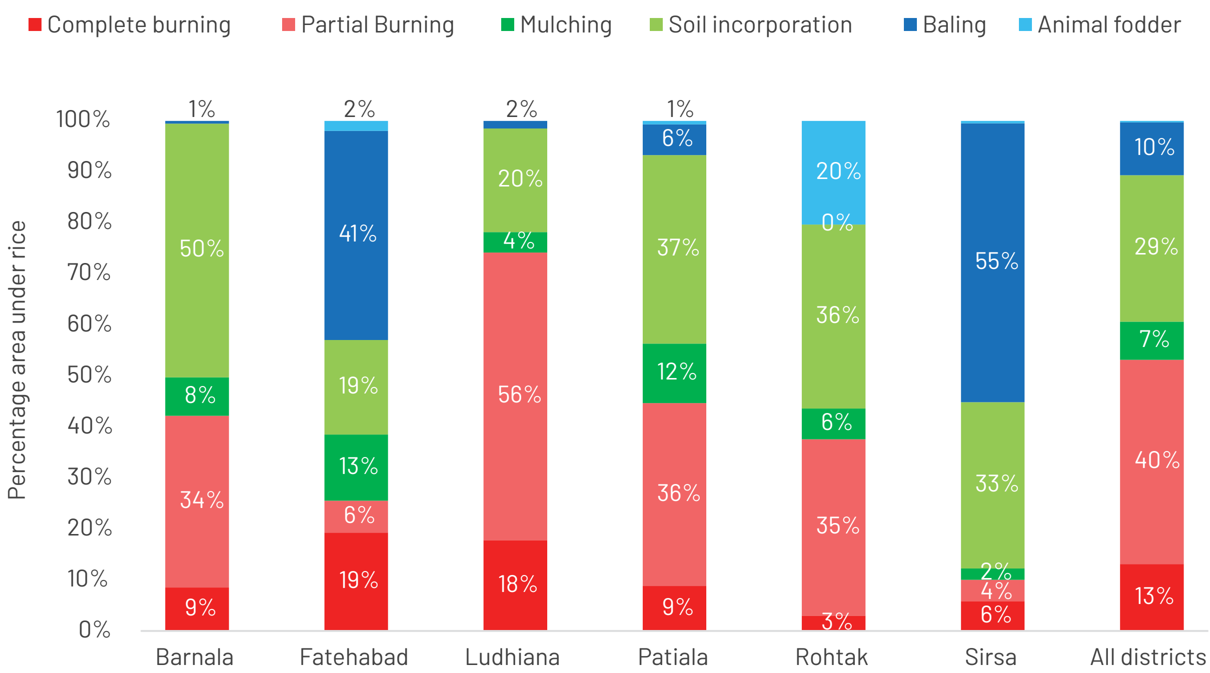
Source: CII Cleaner Air Better Life (2020) Analysis

Note:
1. Other methods include collection for local use such as mushroom farming and composting
2. Different possible combinations of above mentioned methods are referred as 'Combination of methods

who practiced in-situ management including mulching and soil incorporation. Soil incorporation constituted the largest share of these two at 81% of all farmers practicing in-situ management. Additionally, there are 10% farmers relied on ex-situ management or baling for crop residue management. A large proportion of farmers, 34% of all farmers, partially burnt the excess straw while using the rest for in-situ management. Partial burning is found to be one of the biggest inherent challenges with adoption of in-situ management practices where 100% direct reuse of straw is not always possible due to various operational challenges faced at field. In intervened geographies, these farmers burnt 30% of excess straw on average while utilising majority of straw for soil incorporation or mixing using either rotavator or reversible mould board (MB) plough.

Further, the adoption of practices across districts and landholding size classes are being plotted in Figure 6 and Figure 7 respectively. As shown in Figure 6, the overall results on technology adoption vary significantly across districts. In four out of six clusters in districts of Barnala, Patiala, Rohtak and Sirsa- complete burning was limited to less than 10% of farmland and improved CRM practices were tried by farmers on more than 90% of farmland. Significantly higher baling in observed in Sirsa and Fatehabad due to hard soils which makes operation of in-situ implements very difficult for farmers and higher straw-to-grain ratio associated with particular rice variety (PB 1401) grown by farmers in this region. Balers were provided to farmers in this region as a key viable option to manage crop residue along with in-situ management. Relatively higher incidents of burning as well as partial burning were recorded in Ludhiana cluster. This is due to the restriction placed by concerned farmer group for farmer access to tool bank. With the intention of curbing crop residue burning altogether,

Figure 6. Adoption of practices across intervened geographies in six districts



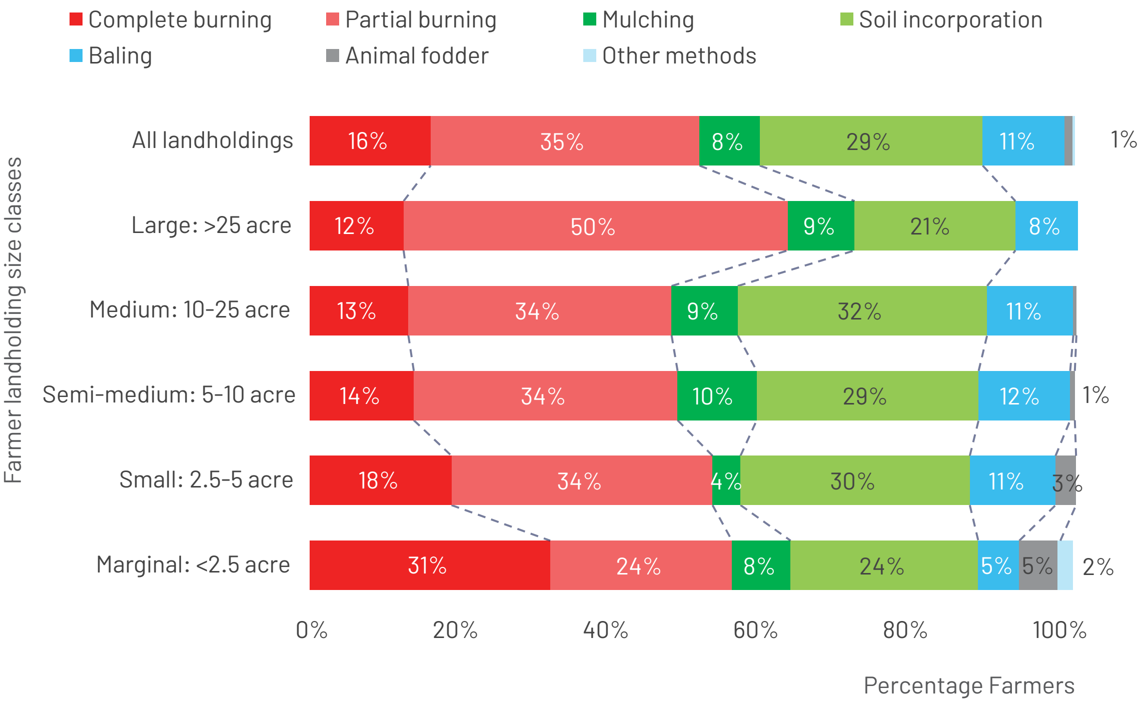
Source: CII Cleaner Air Better Life (2020) Analysis

Note: 'Partial burning' is limited burning (30% rice straw on average) followed by in-situ management (soil incorporation). Refer Figure 10 for actual burning across intervened areas in each district.

farmer group did not allow access of farm tools if even farmer burnt small extent of straw along with direct reuse at field. On contrary, this led to lower adoption in rural cluster of Ludhiana. This indicates a strong and urgent need of pragmatic solutions to farmers who can not utilise 100% rice straw. Overall, relatively higher burning incidents are observed in Punjab geographies compared to Haryana in 2019.

As seen in Figure 7, significant number of farmers across all size classes participated in the programme and used improved crop residue management practices. From Figure 7, it clearly stands out that 50% large farmers practiced partially burning of residue before utilising it at field compared to 24-35% farmers who followed the same practice across other size classes. This is quite evident due to higher amount of efforts and time needed to clear large fields. Large farmers need feasible solutions to move towards 100% in-situ/ex-situ from partial burning as they need more time to clear fields of standing stubble in short time window between harvesting rice and sowing next crop. Also, as depicted in the same figure, marginal farmers (31% vis-a-vis 12-18% across all other size classes) practice complete burning more often compared to other size classes due[4] to smaller plot area which can be cleared with burning rather quickly and poor access of such farmers to high-power tractors, training and finances. Share of ex-situ is also the lowest among them due to higher cost involved in baling for clearing the fields.

Figure 7. Adoption of practices across different landholding size classes



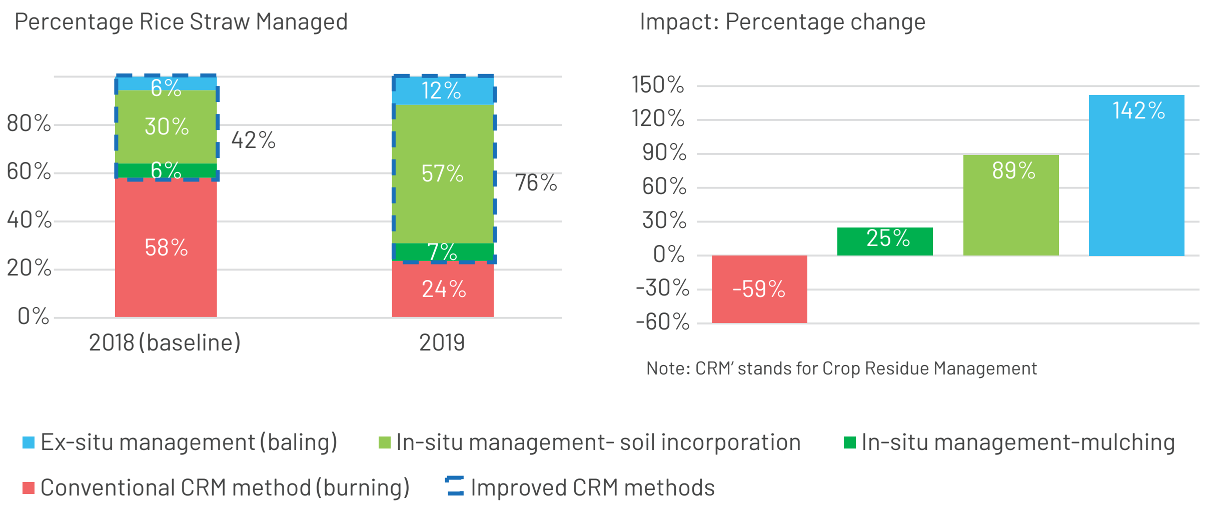
Source: CII Cleaner Air Better Life (2020) Analysis

[4]It should be noted that differences are not significant across size classes when farming area is used a common basis for similar comparison.

Total rice straw managed under different practices is used as common basis to calculate adoption of different practices and technologies in intervened geographies. Figure 9 shows how rice straw was managed in the baseline (2018) and year of intervention (2019) for which impact assessment is carried out. It also shows the results for newly intervened (86 villages) and previously (16 villages) intervened villages separately. On the basis of this information, pace of technology adoption was calculated. Figure 8 provides an overview of this for 102 villages and shows the actual impact of CII's CRM programme in 2019. Overall impacts on extent of burning and adoption of new technologies across Punjab and Haryana include-

- Overall, the crop residue burning was reduced from 58% rice straw burnt in 2018 to 24% rice straw burnt in 2019 in CII intervened areas. These figures also include the straw which is partially burnt along with in-situ use. This meant overall 59% decline in extent of rice straw burning across intervened geographies
- The overall adoption of improved CRM practice went up by 83% in intervened area. While in-situ mulching did not see a significant increase (+24%) in adoption this year, the adoption of in-situ soil-incorporation (or mixing) and ex-situ or baling significantly increased by 89% and 142% respectively within one year of intervention.

Figure 8. Impacts of CII programme in 2019 for curbing crop residue burning and accelerating adoption of improved Crop Residue Management (CRM) practices



Source: CII Cleaner Air Better Life (2020) Analysis

Note: 'CRM' stands for Crop Residue Management

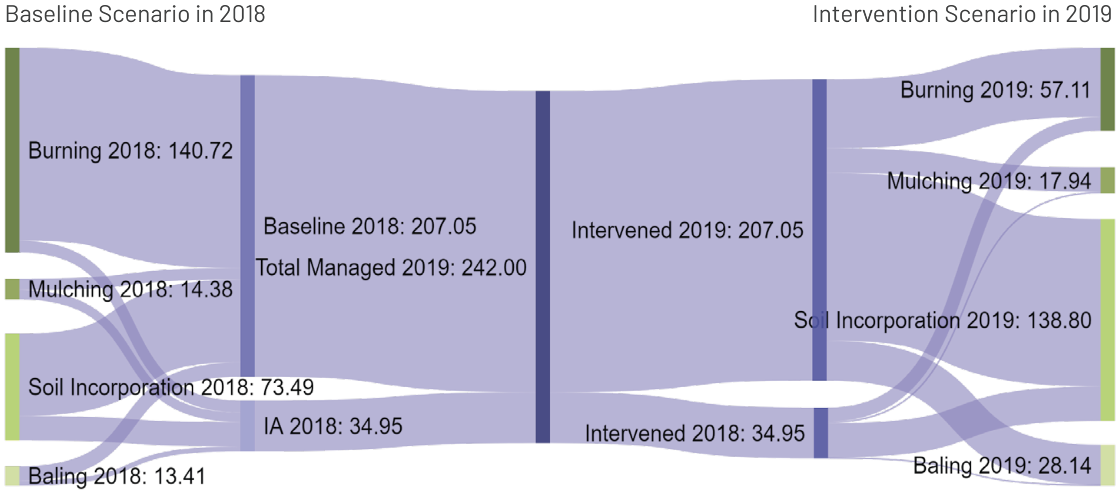
Table 1. Tool combinations and methods used by farmers in 102 villages across Punjab & Haryana for conventional as well as improved crop residue management practices

Practices	Methods	Percentage share	Fuel Consumption [litre/acre]	
			Method-wise	Practice-wise
In-situ Management: Mulching	(a) Happy Seeder	43%	7.25	11.08
	(b) Mulcher + Happy Seeder	36%	15.25	
	(c) Super SMS + Happy Seeder	21%	11.75	
In-situ Management: Soil Incorporation	(a) Rotavator SD	72%	8.07	11.24
	(b) Mulcher + Reversible MB Plough + Rotavator SD	15%	23.88	
	(c) Mulcher + Rotavator SD	5%	16.07	
	(d) Rotavator + Zero Till SD	4%	12.66	
	(e) Super SMS + Rotavator SD	3%	12.57	
	(f) Reversible MB Plough + Rotavator SD	1%	16.69	
Ex-situ Management: Baling	(a) Cutter + Raker + Baler + Rotavator SD	65%	20.13	23.10
	(b) Cutter Raker + Baler + Disk Harrow + Cultivator + Leveller + Zero Till SD	35%	28.65	
Conventional Methods: Crop Residue Burning	(a) Cutter + Burning + Rotavator SD	60%	11.07	14.52
	(b) Cutter + Burning + Disk Harrow + Cultivator + Leveller + Zero Till SD	40%	19.59	

Source: CII Cleaner Air Better Life (2020) analysis of primary data

Note: Only combinations with ≥1% share among all farmers in 102 villages have been considered here, ignoring various other existing combinations which will be insignificant for this assessment and cost analysis under Section 4.3.

Figure 9. Comparison of rice straw management scenario across 102 villages in 2018 (baseline) and 2019 (Intervention)



Source: CII Cleaner Air Better Life (2020) Analysis

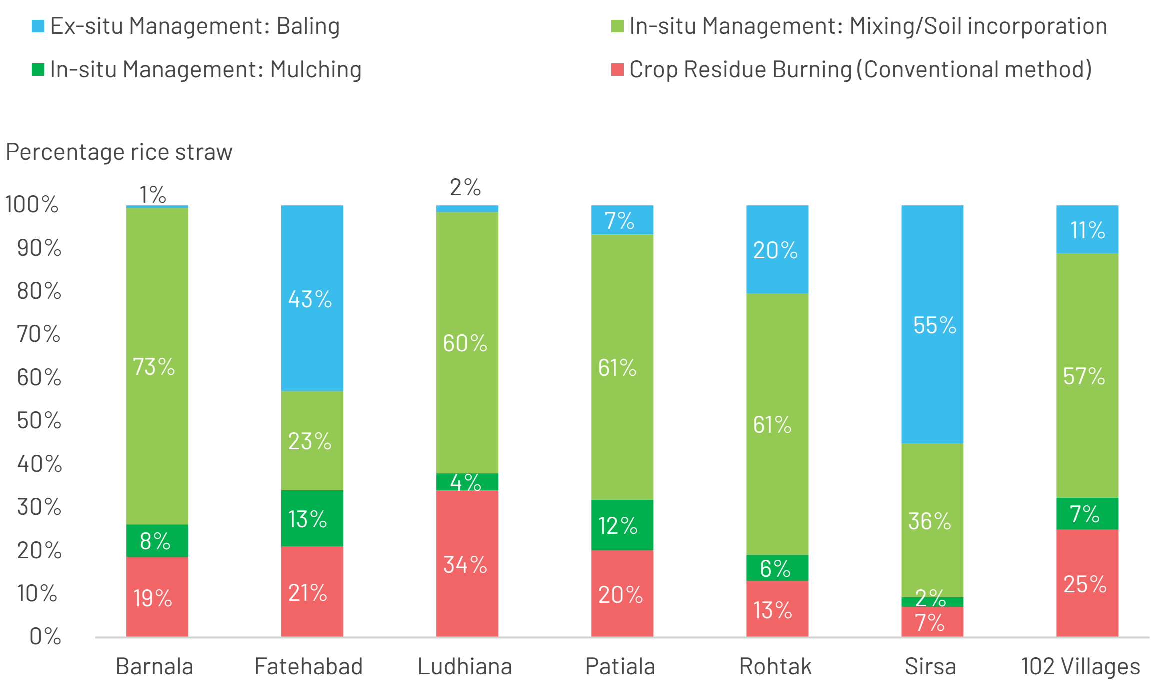
Note:
1. The indicated quantities of rice straw are in 'thousand tonne' units
2. The node named 'IA 2018' stands for Impact Assessment of programme in 2018

4.2 Environmental Impacts

Crop residue burning severely impacts air quality adding to public health expenditure and loss of life. Living in areas with intense crop residue burning is associated with three-fold increase in acute respiratory infection (Chakrabarti et al 2019). Chakrabarti et al 2019 also estimates that economic value of DALYs[5] saved by averting crop residue burning in North West India will be INR 10500 Crore over 5 years. Environmental impact of CII's field interventions is directly linked to avoided burning of 183 thousand tonne rice straw due to large scale adoption of improved crop residue management practices by farmers in intervened communities. Results of impact assessment study indicate that overall, 75% rice straw generated in 102 villages was avoided from burning. District-wise details for each intervened rural geography can be seen in Figure 10.

As noted in literature approximately 2.5-4.77 tonne rice straw is generated from a paddy field spanning one acre (Kumar et al 2015). Using a conservative estimate of 2.5 tonne rice straw/acre, total rice straw which was avoided from burning amounts to 183 thousand tonne rice straw across 102 villages. Figure 11 shows how this avoided burning was spread geographically across North Western states.

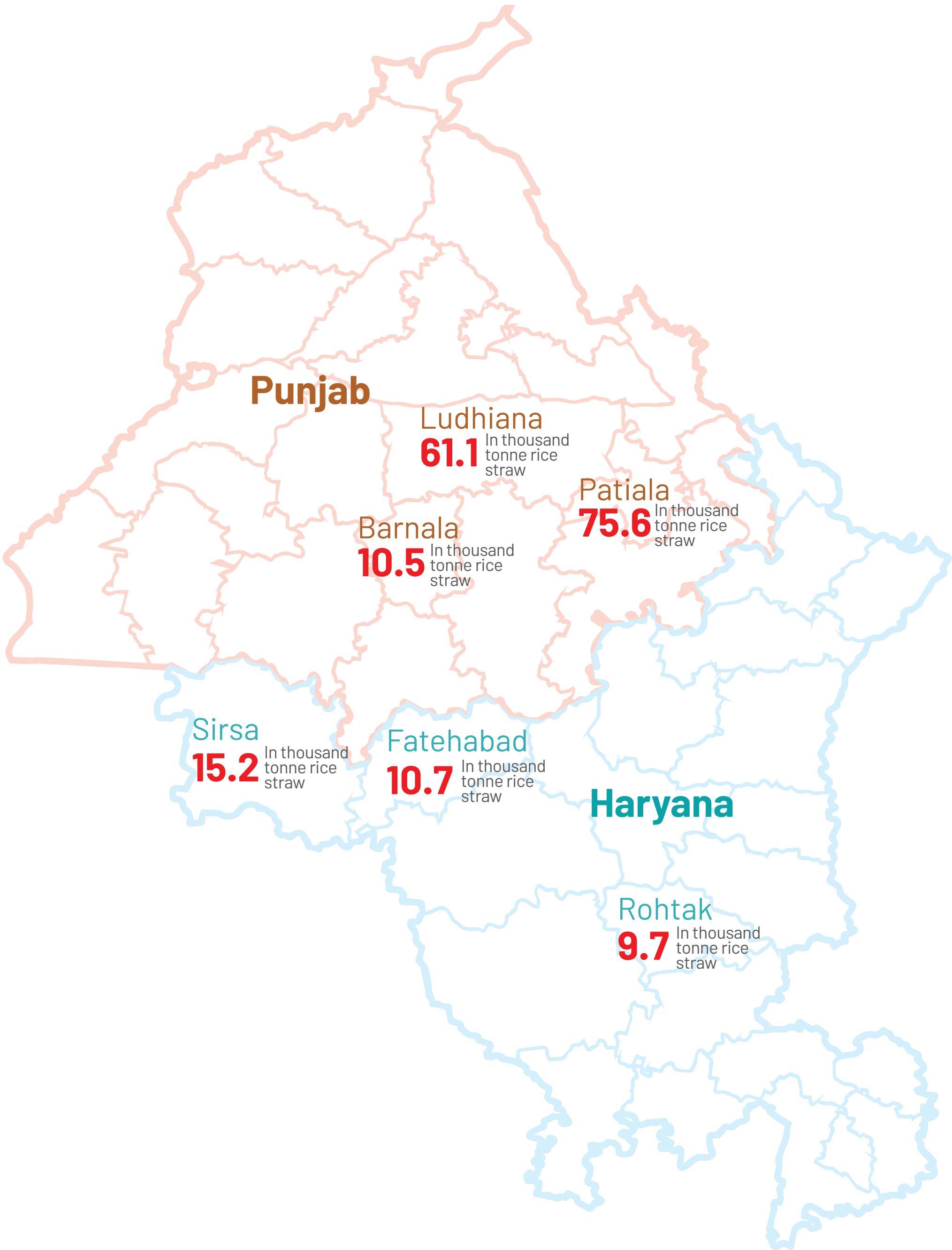
Figure 10. Share of Crop Residue Management practices by amount of rice straw managed in intervened geographies



Source: CII Cleaner Air Better Life (2020) Analysis

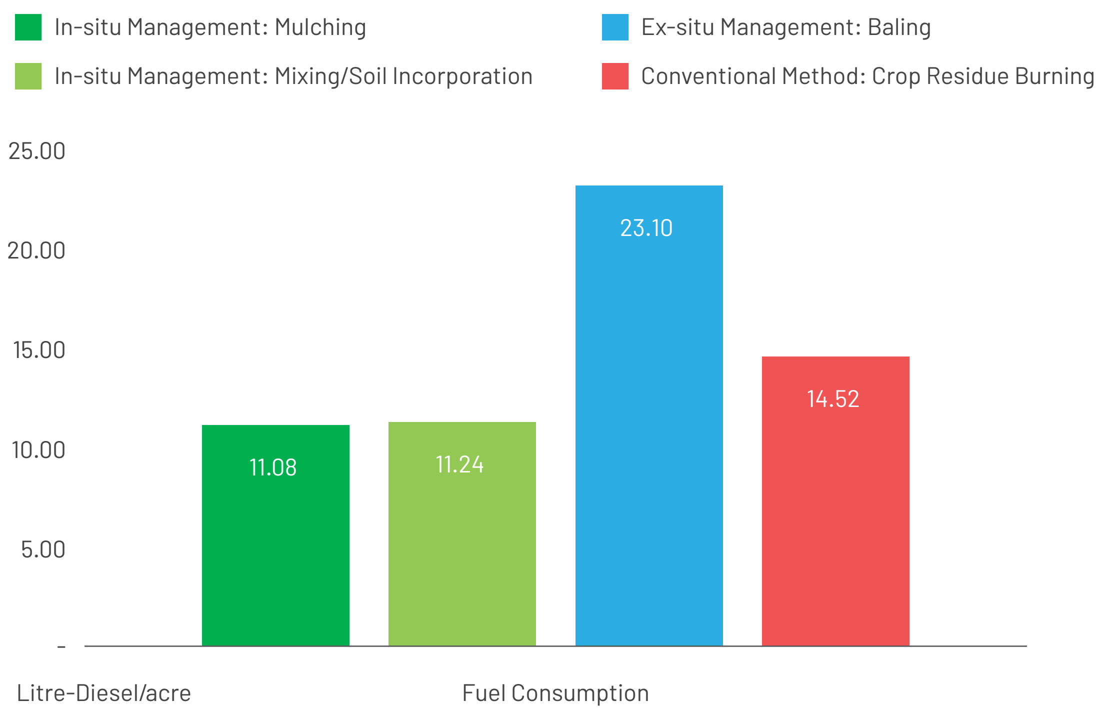
[5]Disability adjusted life years (DALY) is measure of burden of decease from air pollution

Figure 11. Avoided crop residue burning (in thousand tonne rice straw) across intervened geographies in 2019



From environment and health perspective, fine particulate matter (with size below 2.5 µm or $PM^{2.5}$) emissions are most critical in terms of their health impacts (WHO 2019) and can travel to far away distances (in a matter of few days to weeks) causing environmental and health impacts at local, regional and global scales. Black carbon (BC) emissions, which again form a part of PM2.5 emissions, are Short-Lived Climate Pollutants (SCLPs) and cause radiative forcing. Based on quantification of programme data avoided burning across 102 villages amounts to 183 thousand tonne rice straw. Based on emission methodology adapted from Singh et al (2020) and Shrestha et al (2012), primary particulate matter emissions worth 1.29 thousand tonnes of suspended particulate matter (PM10) are avoided as a result of field intervention. Avoided primary particles included total 770 tonne fine particulate matter ($PM^{2.5}$) emissions. Besides primary particles, gaseous pollutants (VOCs, SOx, NOx etc.) amounting 3 thousand tonnes in total, with potential to travel across the region and lead to secondary particles, are avoided. See Table A1 in Annexure 1 for more details of various components of avoided air pollution and their health impacts. Fuel consumption in field operations and as a result, the onsite diesel emissions are also significantly lower in the case of in-situ management practices (mulching and soil incorporation) adopted on 65% of intervened land or 62694 acres of agricultural area (7% mulching and 57% soil incorporation) under rice. Through primary data on farm inputs/outputs, method-wise as well as practice-wise fuel consumption was calculated for 102 geographies as given in Table 1. Practice-wise fuel consumption is summarised in Figure 12. Both in-situ practices have similar fuel consumption which is found to be 23% lower than conventional practice of burning. Fuel consumption of ex-situ (baling) management is twice compared to in-situ management and 1.6 times the crop residue burning. Using diesel consumption as proxy for cost and emissions, same conclusion can be drawn for on-field diesel emissions and fuel cost. This is especially due to the fact that multiple tools and field runs (extensive tillage) are required under conventional (burning) methods as noted in Table 1 as compared to conservation tillage system e.g. mulching with happy seeder.

Figure 12. Fuel consumption across practices widely adopted with burning as baseline

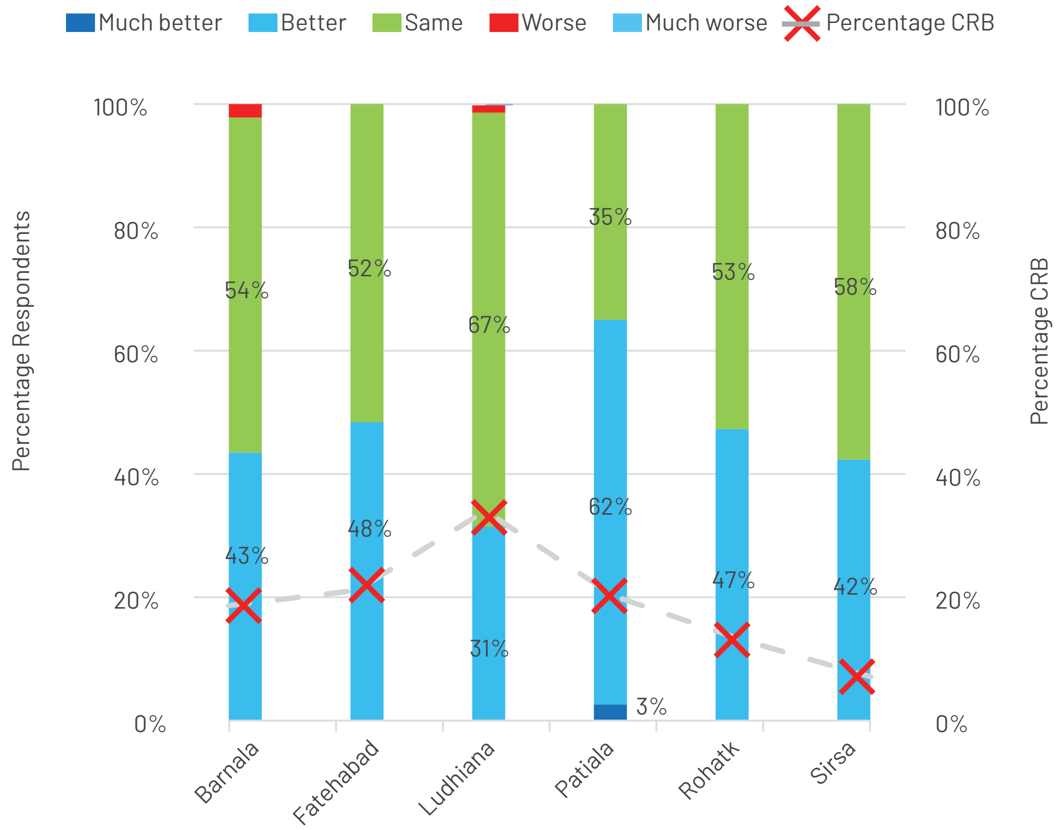


Source: CII Cleaner Air Better Life (2020) Analysis

Further, using global warming potentials (g CO_2e/g GHG) from Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report (Myhre et al 2013), it is estimated that Greenhouse Gas (GHG) emissions worth 0.2 million tonne CO_2e are saved[6] across intervened area in 2019. In addition to these GHGs, 86 tonnes of BC are avoided as part of $PM^{2.5}$. BC is short-lived climate pollutant and despite its short atmospheric lifetime, it is one of the largest contributors to global warming after CO_2. It also known to decrease agricultural yields and accelerate glacier melting (Myhre et al 2013, WHO 2019).

Farmer households in intervened areas were asked in the assessment whether these activities resulted in first-hand experience of better air quality compared to the previous year when burning was more prevalent. These responses are plotted in Figure 13 along with extent of rice straw which was still managed through conventional practice of CRB. Direct correlation between the two can be seen in the figure. Ludhiana areas where results were relatively worse at 34% burning, only little over than 30% said that air quality was better than last year. Patiala where bulk of villages were adopted with 80% straw managed through improved straw management practices (56 out of 102 intervened), highest number of responses (65%) were received for better air quality while rest of the households (35%) perceived no change from last year. In Sirsa geographies, where least amount of straw was managed through burning (7%), 42% farmer households perceived air quality

Figure 13. Perception of Farming households on air quality improvement in their communities



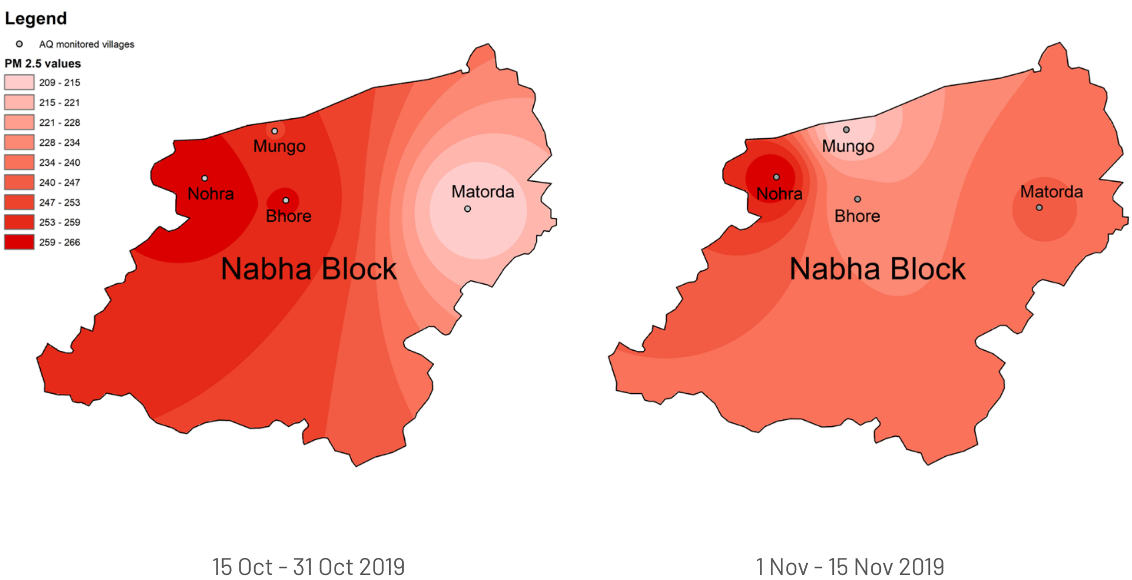
Source: CII Cleaner Air Better Life (2020) Analysis

Note: CRB Stands for Crop Residue Burning

[6]Only carbon dioxide and methane emissions which are two of the most potent GHGs are accounted for GHGs

was better than last year. A large number of respondents (58%) mentioned no change in these 8 villages as they are geographically scattered across rice growing belt of Sirsa and crop residue burning in nearby areas may have led to this outcome. Such inherent challenges in delinking outside contributions are also experienced with limited data points from sensors-based monitors and lack of reference station in proximity. Figure 14 summarises the air quality situation ($PM^{2.5}$ concentrations) in peak season (15 October 2020-15 November 2020) in intervened and non-intervened villages, monitored using four sensor-based PM monitors in each village. The map is generated using the 'inverse distance weighted' interpolation technique where cell values are estimated by averaging the values of sample data points (four PM monitors) in the neighbourhood of each cell. The figure shows significant differences in air quality measured during peak period. Nohra which is the only village without intervention recorded 20% and 36% higher $PM^{2.5}$ in two consecutive periods (15 October-31 October, 2019 and 01 Nov-15 Nov, 2019 respectively) compared to average $PM^{2.5}$ concentrations across intervened villages (Bhore, Matorda and Mungo) as shown in the map. Due to transboundary nature of air pollution (air getting mixed all the times) and dynamic change with external (weather) factors, it is difficult to narrow down the impact of interventions as part of this study's scope. Building combination of approaches using remote sensing, climatology, infrared imaging and sensor-based monitors, field verifications etc. is a future endeavour to be able to disentangle emissions originating inside and outside a village/cluster for better monitoring of CRM.

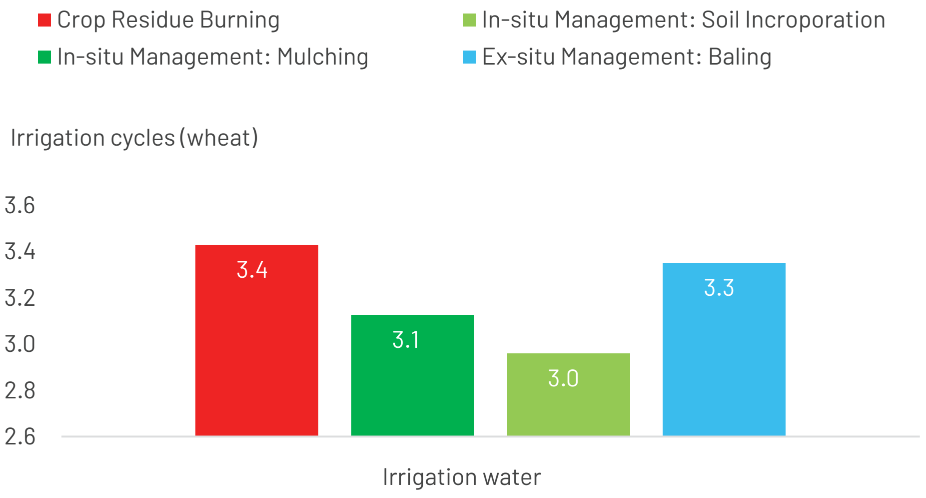
Figure 14. Comparison of measured air quality data in intervened (Bhore, Matorda and Mungo) and non-intervened (Nohra) villages of Patiala district



Source: CII Cleaner Air Better Life (2020) Analysis

Water savings are especially relevant for North Western States where replenishment rate of ground water is well below the withdrawal rate and many districts have experienced a decine in the water table of over 0.50 meters per year, reaching critical levels (Paroda et al 2018). Primary data on irrigation applied in subsequent crop was collected from farmers across intervened villages and results are plotted in the Figure 15. These findings also corroborate with estimated water savings in previous year's impact assessment study (Sharma et al 2019) and synthesis of secondary literature (Lohan et al 2017; Sidhu et al 2015; Singh et al 2011). The analysis establishes the water saving during the crop growth phase at 13% of total requirement under conventional practice (CRB), if farmer utilises the crop residue in the field or in-situ. As seen in Figure 15, it is further established that water requirement does not change significantly across conventional (burning) and ex-situ (baling) practices. No evidence could be generated for pre-sowing irrigation requirement across new geographies, although previous year's impact assessment as well as secondary literature suggests that pre-sowing irrigation water requirement for wheat which is 75-100 mm is eliminated in the mulched fields (Sidhu et al 2015). The key reason for no concrete evidence on this is expected due to higher precipitation humid conditions this season and very low uptake of mulching. Using primary data from farmers and considering savings during the plant growth phase alone, total water savings in intervened geographies are calculated. It is found from analysis of primary data that 10.15 billion litres of water savings are achieved in intervened geographies as a result of improved crop residue management practices.

Figure 15. Irrigation water requirement across CRM Practices



Source: CII Cleaner Air Better Life (2020) Analysis

4.3 Economic Impacts

One of the key objectives of CRM programme is to create shared-economy model in rural communities to address fundamental challenge of affordability of tools needed by farmers for only few hours to few days in the entire year. Under shared-economy model, farmer groups take responsibility of upkeeping of provided tools and ensure that all farmers in the village get to use the machines on payment of a nominal rent. Farmer groups, especially FSCs, often provide credit linkages to farmers.

The Figure 16 depicts the situation of farmers' access to various tools being used across rural geographies for improved crop residue management practices. The green coloured bars in figure indicates the share of farmers accessing shared-economy model created by CII with farmers groups. While the mentioned tools are used in various combinations by farmers, some of these are also utilised under conventional practices i.e. bottom two tools in figure- rotavator and Zero-Till (ZT) machine. Majority of farmers own these tools and as clear from primary data in Figure 16, these tools enjoy better penetration and are rarely accessed through farmers groups. Top two tools in Figure 16 i.e. baler and super SMS are usually provided by machine aggregators, service providers or private agencies who rent combine harvesters (super SMS attaches to combine harvester) to farmers. In 2019, few balers were provided to farming communities on need basis[7] and this evident in the figure. Middle three tools in Figure 16 i.e. mulcher, happy seeder and (reversible) mould board plough are used the most for in-situ management. Key conclusions can be drawn from Figure 16 in this respect are-

1. Penetration of in-situ management tools, which are exclusively used for in-situ management, is evidently still low among farmers for reasons explained in the beginning of this section. Few farmers and only medium-large farmers can afford to own these tools.

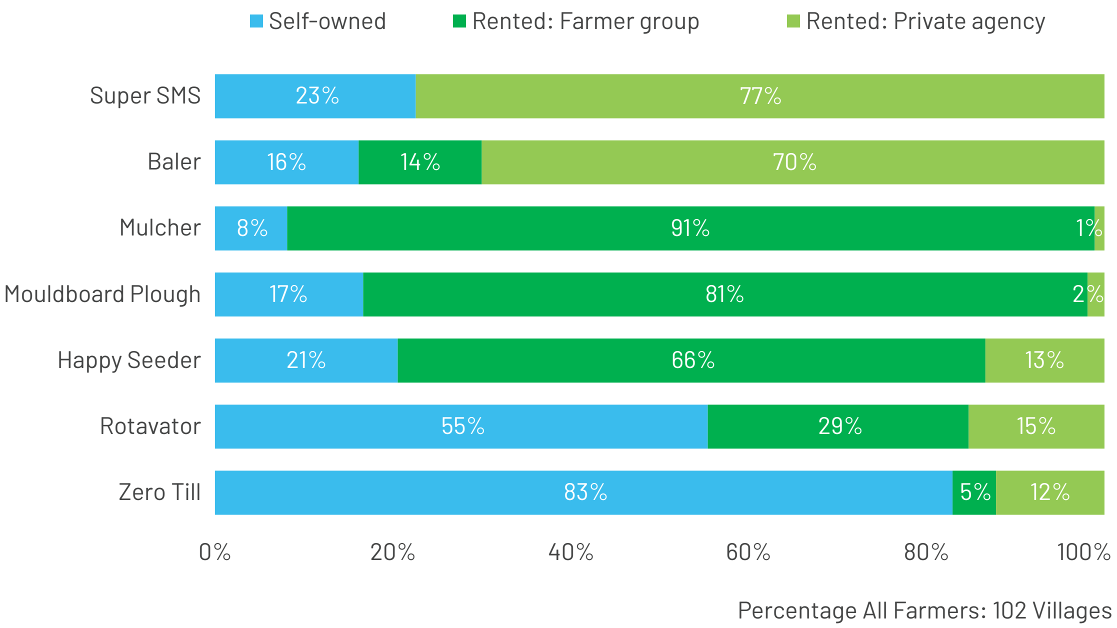
2. In-situ management is promoted with farmers under CRM programme due to their huge environmental as well as soil health benefits. It is quite evident from farmer data that In-situ management tools were accessed by farmers the most though shared-economy model (Mulcher at 91%, MB Plough 81% and happy seeder at 66%) created by CII with farmer groups (FSCs and FPOs).

3. The low rate of renting happy seeder through farmers group is evident. This is due to lower adoption of mulching. Happy seeder is key tool used for mulching and it can be used alone or in combination with other tools depending on farmers preferences and field conditions. Despite, significant time and fuel savings over other methods, relatively low adoption of happy seeder is due to multiple factors leading to confusion among farmers which affected their perception and technology choices. Change in weather patterns in current season led to pest-related challenges in few fields with standing layer of mulch on ground. But focussed group discussions with farmers and analysis of primary data (in subsequent sections) shows us that actual cases of pest were limited to very few plots.

4. A small contribution of private agencies in this category of tools is not necessarily due to involvement of external private parties. There are a small group of farmers in a village with private ownership of these tools, who rent these out to other farmers in same or nearby communities and villages

[7]In area with hard soils where in-situ operations are challenging and large share of vegetable farmers who do not find in-situ management cost-effective.

Figure 16. Situation on access to farm tools in intervened geographies



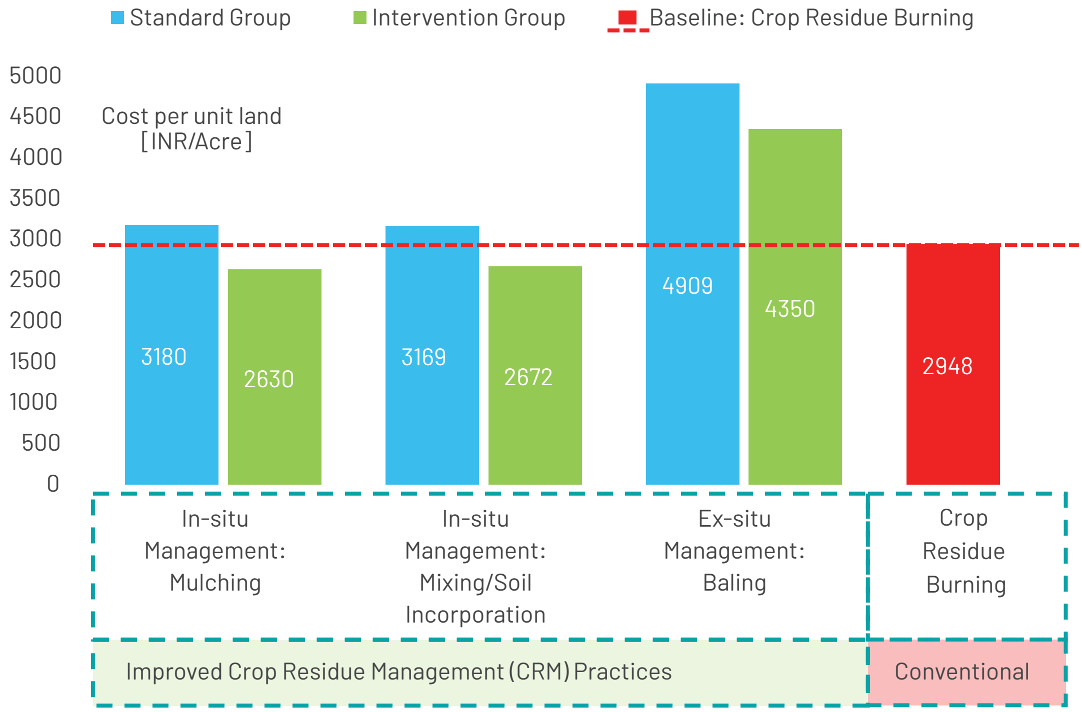
Source: CII Cleaner Air Better Life (2020) Analysis

The cost of "harvesting rice, field preparation and sowing for the next crop" farmers choice of CRM methods. All of these operations take place in a short time window spanning few weeks. Many farmers seek credits from farmer groups to avail services such as tractors, farm implements, seed drills etc. Primary data collected from farmers on tools rents, labour charges, field capacities, fuel consumption etc. were utilised to build robust cost analysis which helps us understand farmers' perspective and cost dynamics which guide their decision to burn or shift to a new practice. Total cost of these operations consists of cost of renting implements, tractor, labour and fuel consumption for these operations. As harvesting rice is the common denominator across all methods (all methods and tools combinations, mentioned in Table 1, are preceded with combine harvester operation), combine harvester has been dropped from cost analysis but additional expenditure of attaching super SMS to combine harvester i.e. higher fuel consumption, lower field capacity of combine harvester etc. are also considered. The overall cost is also referred as the cost of crop residue management in the report.

The primary data from 16% farmers, who managed post-harvest remains of rice through burning in intervened areas and FGDs with farmers, were used to build the baseline cost (cost of crop residue burning) for this analysis. Utilising cross-sectional data from farmers across two different scenarios are created to analyse the actual cost of CRM to farmer-

1. Interventions group: This group represents the shared-economy model. These are the farmers who accessed tools from farmer groups in intervened areas and are part of 84% farmers who did not burn in CII intervened areas of Punjab as well as Haryana. They had to pay lower cost for accessing needed farm tools. Actual share of tools and methods from 102 intervened village was used to build representative cost of practices across intervened geographies.

Figure 17. Cost of Crop Residue Management (CRM) practices



Source: CII Cleaner Air Better Life (2020) Analysis

2. Standard group: tool rents from private agencies were used as a proxy for cost for CRM to farmers outside intervened area or a standard group without any intervening agency i.e. farmer group, community organisation, NGO etc.

The results of cost analysis are shown in Figure 17. Key results of cost analysis can be summarised as below -

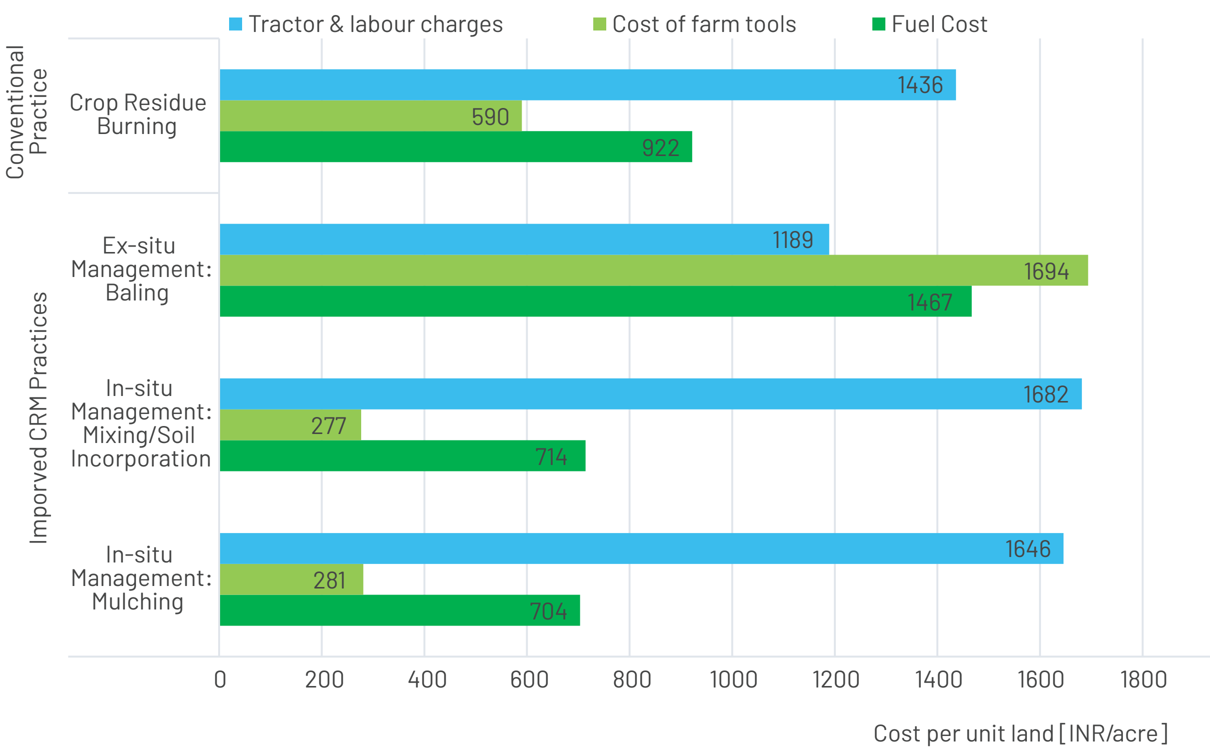
1. Contrary to popular belief that Crop Residue Burning (CRB) does not cost farmer, CRB costs farmer INR 2948 per acre on average as per farming data from 102 villages of Punjab and Haryana under this study.

2. Under the shared economy model (intervention group), in-situ CRM practices cost 10% lesser than per unit cost of Crop Residue Burning (CRB). Results are consistent with preliminary findings of Sharma et al 2018 and mulching (in-situ) is the most cost-effective method (11% lesser cost compared to CRB) for farmers. Soil incorporation (in-situ) is not far behind in term of cost at 9% lesser than CRB. The same is not true for standard group across two North Western states, where in-situ costs 7-8% more compared to CRB. This indicates that there is a definite room for improvement in implementation of Central Sector Scheme on in-situ technologies.

3. Under standard group, Ex-situ baling costs 67% more than the cost CRB. Even under the shared economy model or intervention group, ex-situ costs 48% more (INR 4350/acre) compared to CRB. Scaling ex-situ solutions therefore requires significant intervention to exploit economy-wide circularities and bridge the gap between in-situ crop residue management solutions and air pollution.

The detailed breakup of costs for crop residue burning and different methods under the standard group is provided in Figure 18.

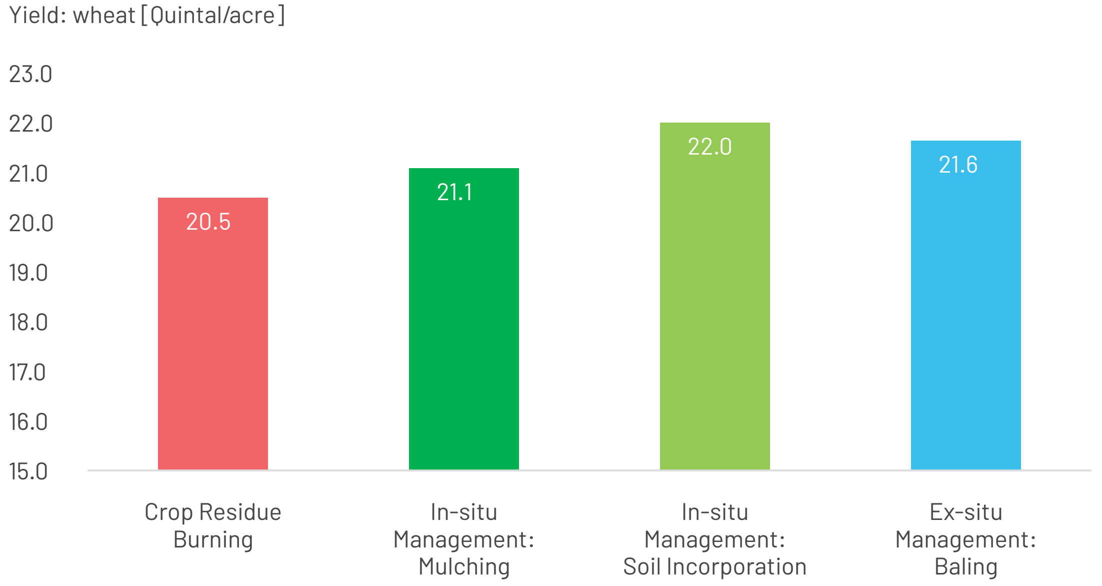
Figure 18. Break up of cost for crop residue burning and improved crop residue management practices under intervention group



Source: CII Cleaner Air Better Life (2020) Analysis

Productivity of subsequent crop (rabi crop sown immediately after rice) is another major concern of farmers which affects his choice of methods for crop residue management. A major focus after implementation is therefore to ensure throughout the crop (rabi) growth stage that farmers get the same or higher level of productivity under new set of practices. Without this crucial link, farmer initiative will not be sustainable for future. Reusing the straw in-field improves the system-wide performance of agricultural operations extending which goes beyond the nutrient recycling. Complex soil dynamics imply that benefits after switching from year of burning are not immediate it takes some time for soil health to improve after application of crop residue. Synthesis of secondary literature review indicates that the in-situ management of rice straw is estimated to improve the wheat crop yield by 2-10% (Kumar et al 2015, Sidhu et al 2015, Aryal et al 2016, NAAS 2017, Kakraliya et al 2018, Ram et al 2018 and Jat et al 2019) but this improvement is gradual and takes few year to manifest. Also, given the complex relationship between climate factors, farm inputs and productivity, there is a need to understand the full cost of CRB vis-à-vis improved CRM practices.

Figure 19. Wheat yield in 2020 for farmers following different set of practices



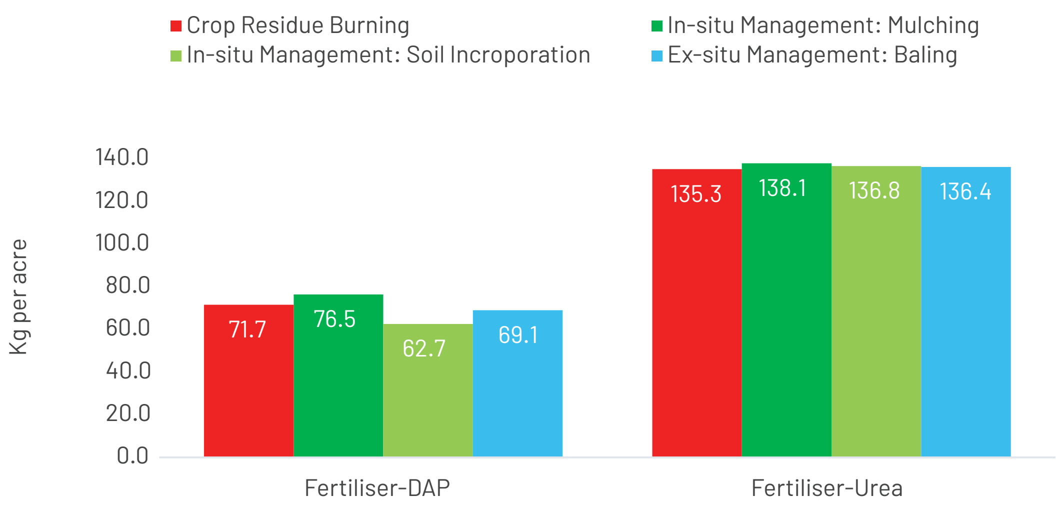
Source: CII Cleaner Air Better Life (2020) Analysis

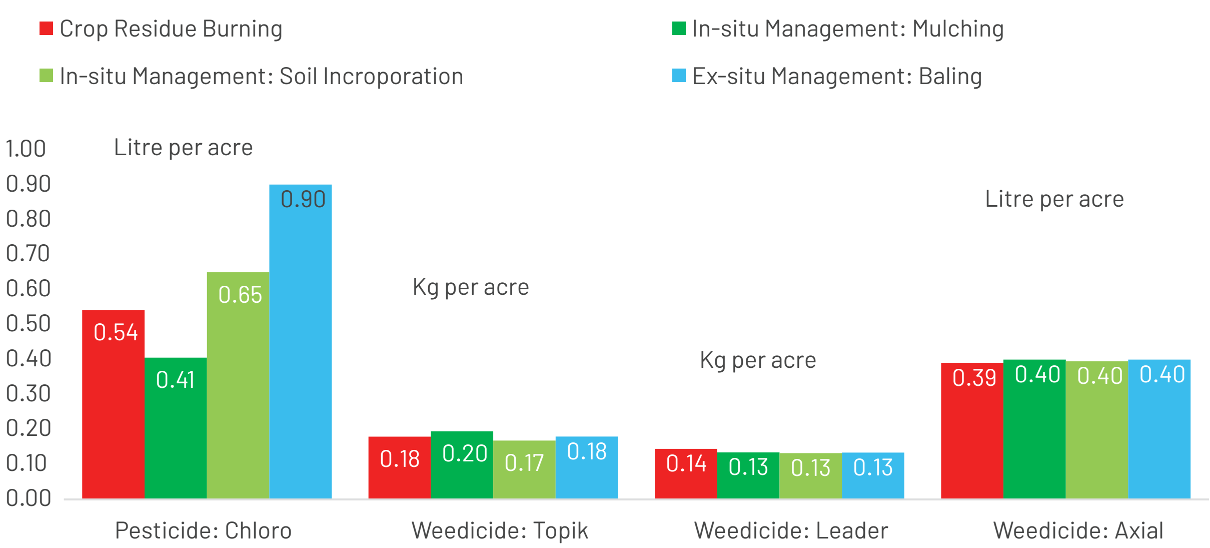
Improved CRM practices took place on significant land in the base year (2018)- on average 42% farmland of all villages. Land under new practices was much higher (76% farmland) in 16 villages already intervened in 2018 while it stood at 36% farmland for 86 villages intervened in 2019 for the first time. As a result, yield has shown significant and noticeable improvement compared to last year.

Cross-sectional yield (wheat) data was acquired from farmers in June 2020, those burnt rice straw and those who adopted alternate CRM options, is compared in Figure 19. Contrary to farmers' perception of mulching, it gives 2.93% higher yield in next crop compared to plots where rice straw was cleared with CRB in 2019. Moreover, 7.32% higher yield is achieved by farmers practicing soil incorporation which supports the fact that soil incorporation is a preferred in-situ management option by farmers (See Figure 10) despite comparable and slightly higher cost (See Figure 16). Wheat yield from plots under baling (ex-situ) in 2019 is also found to be significantly higher (5.37%) compared to those managed with CRB.

As reported in last year's impact assessment, nitrogen immobilisation may lead to higher consumption of urea in mulched fields. Nitrogen immobilisation is a temporary phenomenon and occurs especially when farmer switches from burning (for many years) to application of crop residue in field. Phenomenon is linked to increase in the soil organic carbon which ultimately leads to higher microbial activity, healthier soils, and higher use efficiencies of fertiliser and water with higher farm productivity in long-run. Fertiliser (urea and DAP) and chemical (weedicides and pesticides) inputs as applied by farmers in plots under different practices are analysed across practices in intervened area are represented in Figure 20. Slight increase in urea and DAP demand due to nitrogen immobilisation in mulched plots is seen in Figure 20. Contrary to normal belief, pesticides application under mulching is found to be much lower compared to other practices in 2019. Pesticides consumption in 2019 is found to be higher in extensive tillage systems and lower in conservational tillage techniques. Weedicide consumption is found to be rather flat across practices and there is no clear evidence of weedicide savings in mulched plots.

Figure 20. Chemical Inputs under the set of agricultural practices





Source: CII Cleaner Air Better Life (2020) Analysis

Farmers' perception and awareness is further assessed by getting their response (on Likert scale of 5) on whether the chemicals' demand goes up, remain stagnant or comes down under new practices. Figure 21 shows farmers' response on weedicides application. In case of baling (ex-situ) and CRB, responses are relatively flat where majority (90%) of respondents take neutral position. Overall, the highest number of farmers (22%) think mulching can reduce weedicide demand. Surprisingly, soil incorporation receives almost similar response (21%) despite the fact that weedicides demand may go up due to disturbances in the topsoil during field operations. This is further support by the fact that the most significant number of farmers (8%) mention higher weedicide demand with soil incorporation. Figure 22 shows results for farmers perception on pesticides. Evidently, there are significant number of farmers (34%) who perceive pests as a threat from mulching, but farmers' perception does not corroborate with actual findings on use of pesticides under mulched plots. This indicate that there is definitely a lot of room to improve farmers awareness on new technologies. No concrete evidence could be drawn on whether the chemical consumption changes significantly as a result of newly adopted practices in 102 villages. Establishing these would requires longitudinal data over longer time horizon. Farm inputs scenario, which is also driven by farmers' perception, is rapidly evolving with adoption of new practices. This demands life cycle cost of CRB vis-a-vis improved CRM practices to understand and inform farmers better towards ensuring long-term sustainability of improved CRM practices.

Figure 21. Farmer perception on changes in weedicide application under different practices

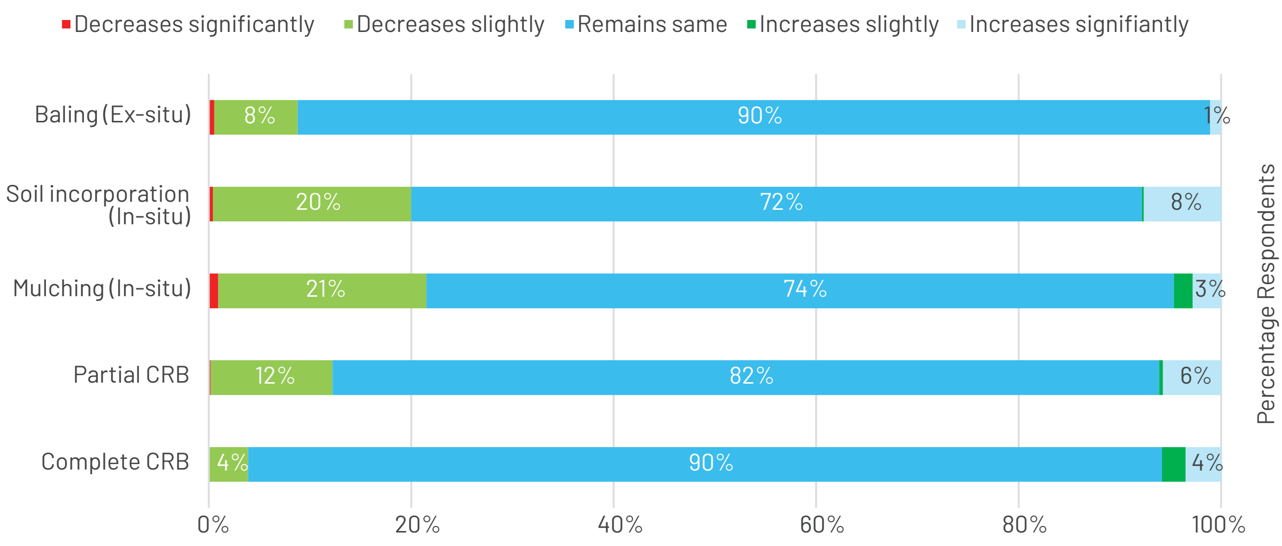
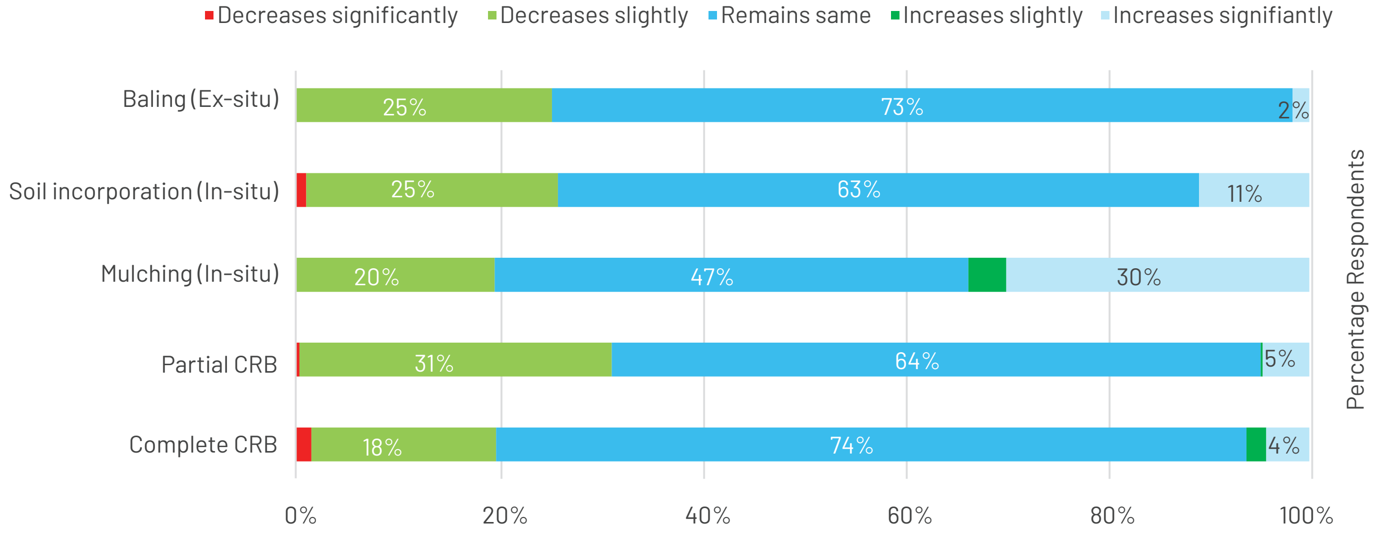


Figure 22. Farmer perception on changes in pesticide application under different practices



5. KEY LEARNINGS

Results indicate a strong need of urgent solutions to farmers who cannot utilise entire rice straw produced at field. In most cases, these situations arise due to field conditions such as crop varieties and soil types. In some of the intervened rural pockets with hard soils, farmers find it difficult to rely fully on in-situ methods and have to apply in-situ either in combination with other methods. Also, in case of sandy or sand loamy soils, farmers with alternate crop rotation (e.g. rice-vegetable-sunflower as opposed to predominant rice-wheat farmers) do not find in-situ management either cost-effective or productive for the next crop. Therefore, ex-situ as an important part of overall biomass management ecosystem, needs to be made more cost-effective or affordable to farmers. Results indicate that even with shared-economy model, incremental cost from burning is much higher for baling.

For large-sized farmers, time taken to clear the fields is most important criterion to decide the course of these activities after harvesting rice. Here again, there is a need to develop capacities for ex-situ as well as address challenges with existing in-situ technologies for 100% direct use at field. While small farmers find it easier to burn in absence of any cost-effective alternate, often he is also proactive in clearing the fields manually if he is able to find value in crop residue through use in composting, animal fodder etc. Multiple solutions therefore need to be explored and deployed for meetings the needs of all farmers in future.

While the adoption of soil-incorporation and baling went up by 89% and 142% respectively from 2018 to 2019, the adoption rate of mulching, at 24%, suffered due to external factors and prevalent perceptions among farmers on risks associated with mulching. The data from ground does not support these perceptions and targeted awareness are needed to communicate the costs and benefits of different methods to farmers. Finally, the farm inputs scenario, which is rapidly evolving with adoption of new practices, is also driven by farmers' perceptions to a significant level. This demands better understanding life cycle costs of CRB vis-a-vis improved CRM practices and communicating these to farmers to ensure long-term sustainability of improved CRM practices.

REFERENCES

Aryal J.P, Sapkota T.B, Stirling C.M, Jat M.L, Jat H.S, Rai M, Mittal S, Sutaliya J.M. 2016. Conservation agriculture-based wheat production better copes with extreme climate events than conventional tillage-based systems: A case of untimely excess rainfall in Haryana, India. Agriculture, Ecosystems and Environment (Elsevier). Issue 233. p 325–335. http://dx.doi.org/10.1016/j.agee.2016.09.013. September 2016.

Jat H.S, Datta A, Choudhary M, Yadav A.K, Choudhary V, Sharma P.C, Gathala M.K, Jat M.L, McDonald A. 2019. Effects of tillage, crop establishment and diversification on soil organic carbon, aggregation, aggregate associated carbon and productivity in cereal systems of semi-arid Northwest India. Soil and Tillage Research. Science Direct. Volume 190. Pages 128-138. https://doi.org/10.1016/j.still.2019.03.005. July 2019.

Kumar P, Joshi L, Kumar S. 2015. Socioeconomic and Environmental Implications of Agricultural Residue Burning: A Case Study of Punjab, India. Springer Briefs in Environmental Science. ISBN 978-81-322-2146-3. DOI 10.1007/978-81-322-2014-5. https://www.springer.com/gp/book/9788132221463

Lohan S.K, Jat H.S, Yadav A.K, Sidhu H.S, Jat M.L, Choudhary M, Peter J.K, Sharma P.C. 2017. Burning issues of paddy residue management in north-west states of India. Renewable and Sustainable Energy Reviews. Science Direct. 81 (2018) 693–706. http://dx.doi.org/10.1016/j.rser.2017.08.057. August 2017.

Myhre G, Shindell D, Bréon F. M, Collins W, Fuglestvedt J, Huang J, Koch D, Lamarque J. F, Lee D, Mendoza B, Nakajima T, Robock A, Stephens G, Takemura T and Zhang H. 2013. Anthropogenic and Natural Radiative Forcing. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report (5AR) of the Intergovernmental Panel on Climate Change (IPCC). Stocker et al (eds.). Cambridge University Press. 2013. Cambridge, United Kingdom and New York, USA. https://doi.org/10.1017/CBO9781107415324.018. June 2014.

National Academy of Agricultural Sciences (NAAS). 2017. Innovative Viable Solution to Rice Residue Burning in Rice-Wheat Cropping System through Concurrent Use of Super Straw Management System-fitted Combines and Tubro Happy Seeder. http://naasindia.org/documents/CropBurning.pdf. October 2017.

Paroda R.S, Jat M.L, Gautam M, Stirling C.M and Bhag Mal. 2018. Agricultural Policies and Investment Priorities for Managing Natural Resources, Climate Change and Air Pollution. Policy Brief. 4p. Trust for Advancement of Agricultural Sciences (TAAS), International Maize and Wheat Improvement Center (CIMMYT), Indian Council of Agricultural Research (ICAR), the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), and the World Bank Group. https://repository.cimmyt.org/bitstream/handle/10883/19517/59604.pdf?sequence=1.

Ram H., Kumar B., Aggarwal N. and Kaur J. 2018. Resource-Conserving Technologies for Enhancing Resource Use Efficiency and Crop Productivity. In: Sengar R., Singh A. (eds). p 129-145. Eco-friendly Agro-biological Techniques for Enhancing Crop Productivity. Springer. https://doi.org/10.1007/978-981-10-6934-5_7. March 2018.

Chakrabarti S, Khan M.T, Kishore A, Roy D, and Scott S.P. 2019. Risk of acute respiratory infection from crop burning in India: estimating disease burden and economic welfare from satellite and national health survey data for 250,000 persons. https://doi.org/10.1093/ije/dyz022. August 2019.

Sharma M., Sharma K., Yadav P. 2018. CII-NITI Aayog Actions Plan for Biomass Management.https://niti.gov.in/writereaddata/files/document_publication/ReportOfTheTaskForceOnBiomassManagement.pdf. February 2018.

Sharma M., Sahajpal I., Bhuyan A., Chauhan A. 2019. CII Cleaner Air Better Life Impact Assessment Report for Crop Residue Management Project 2018. https://sustainabledevelopment.in/wp-content/uploads/2020/06/1565066178CII-Final-CRM-Impact-Assessment-Report-05Aug2019.pdf. August 2019.

Shrestha R.M, Kim O.N.T, Shrestha R.P, Rupakheti M, Rajbhandari S, Permadi D.A, Kanabkaew T and Iyngararasan M. Atmospheric Brown Cloud (ABC) Emission Inventory Manual, United Nations Environment Programme (UNEP), Nairobi, Kenya. https://stg-wedocs.unep.org/handle/20.500.11822/21482.

Sidhu H.S, Singh M, Singh Y, Blackwell J, Lohan S.K, Humphreys E, Jat M.L, Singh V and Singh S. 2015. Development and evaluation of the Turbo Happy Seeder for sowing wheat into heavy rice residues in NW India. Field Crops Research, 184, pp.201-212. https://doi.org/10.1016/j.fcr.2015.07.025. December 2015.

Singh T, Biswal A, Mor S, Ravindra K, Singh V, Mor S. 2020. "A high-resolution emission inventory of air pollutants from primary crop residue burning over Northern India based on VIIRS thermal anomalies." Environmental Pollution 266 (2020): 115132. https://doi.org/10.1016/j.envpol.2020.115132. July 2020.

Singh B, Eberbach P.L, Humpherys E, Kukal S.S. 2011. “The effect of rice straw mulch on evapotranspiration, transpiration and soil evaporation of irrigated wheat in Punjab, India. Agricultural Water Management, 98(12), pp.1847-1855. https://doi.org/10.1016/j.agwat.2011.07.002. August 2011.

World Health Organization (WHO). 2019. Webpage: Air Pollution. https://www.who.int/airpollution/en/. Accessed: 05 April 2019.

ANNEXURE 1.

Avoided Air Pollution from CRM programme in 2019

Table A1. Air Pollutants Avoided at Source and their associated Health cum Environmental Implications

Category	S.N.	Pollutant	Avoided emissions (tonne)	Heath Implications	Environmental Implications
Coarse particulate matter	01	PM_{10}	1291	• Acute lower respiratory infections • Cardiovascular disease • Chronic obstructive pulmonary disease • Lung cancer	• Fine PM travels and causes air pollution at local, regional and global scales within few days to weeks • BC, a component of $PM^{2.5}$, is one of the largest contributors to global warming after CO2 • Causes smog, affecting visibility
Fine particulate matter	02	$PM_{2.5}$	770		
Gaseous pollutants and precursors to secondary particles	03	Carbon monoxide (CO)	13570	• Dangerous in closed environment • Long-term exposure to low concentrations is also associated with a wide range of health effects. • Increase in CO levels linked to congestive heart failures and hospitalizations	• Precursor to ground level Ozone
Gaseous pollutants and precursors to secondary particles	04	Volatile Organic Compounds (VOCs)	938	• Eyes, nose and throat irritation • Difficulty breathing and nausea • Damage to central nervous system as well as other organs • Some VOCs are carcinogenic	• Precursor to ground level Ozone • Precursor to fine/ultrafine secondary particles
Gaseous pollutants and precursors to secondary particles	05	Ammonia (NH_3)	549	• Cough, phlegm • Wheezing • Asthma	• Precursor to ground level Ozone • Precursor to fine/ultrafine secondary particles
Gaseous pollutants and precursors to secondary particles	06	Oxides of Nitrogen (NOX)	261	• Bronchitis • Asthma • Reduced lung function growth • Exposure linked to premature mortality and morbidity from cardiovascular and respiratory diseases	• Precursor to fine/ultrafine secondary particles

Category	S.N.	Pollutant	Avoided emissions (tonne)	Heath Implications	Environmental Implications
Gaseous pollutants and precursors to secondary particles	07	Sulphur dioxide (SO_2)	39	• Inflammation of the respiratory tract • Affects lung functions • Hospital admissions for cardiac disease and mortality increase on days with higher SO_2 levels	• Precursor to fine/ultrafine secondary particles

CII Cleaner Air Better Life (2020) Analysis based on primary datasets, Singh et al 2020, Shrestha et al (2012), Myhre et al (2013), CPCB (2014), Kumar et al (2015), ALA (2019), WHO (2019)

Note: Emissions are calculated assuming 'dry matter to crop residue ratio' of 0.85 and 'burning efficiency ratio' of 0.87

Confederation of Indian Industry
125 Years - Since 1895

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the development of India, partnering Industry, Government, and civil society through working closely with Government on policy issues, interfacing with thought leaders, and enhancing efficiency, competitiveness and business opportunities for industry.

For 125 years, CII has been working on shaping India's development journey and, this year, more than ever before, it will continue to proactively transform Indian industry's engagement in national development. The premier business association has more than 9100 members, from the private as well as public sectors, and an indirect membership of over 300,000 enterprises from around 288 national and regional sectoral industry bodies.

With 68 offices, including 9 Centres of Excellence in India, and 11 overseas offices in Australia, China, Egypt, France, Germany, Indonesia, Singapore, South Africa, UAE, UK, and USA, as well as institutional partnerships with 394 counterpart organizations in 133 countries, CII serves as a reference point for Indian industry and the international business community.

Confederation of Indian Industry
The Mantosh Sondhi Centre
23, Institutional Area, Lodi Road, New Delhi – 110 003 (India)
T: 91 11 45771000 / 24629994-7 • F: 91 11 24626149 • E: info@cii.in • W: www.cii.in

cii.in/facebook | cii.in/twitter | cii.in/linkedin | cii.in/youtube

CII-ITC Centre of Excellence
for Sustainable Development

CII-ITC Centre of Excellence for Sustainable Development is a not-for-profit, industry-led institution that helps business become sustainable organisations. It is on a mission to catalyse innovative ideas and solutions, in India, and globally, to enable business, and its stakeholders, in sustainable value creation.

It's knowledge, action and recognition activities enable companies to be future ready, improve footprints profiles, and advocate policymakers andlegislators to improve standards of sustainable business through domestic and global policy interventions.

CESD leverages its role of all-inclusive ecosystem player, partnering industry, government, and civil society. It has been a pioneer of environment management systems, biodiversity mapping, sustainability reporting, integrated reporting, and social & natural capital valuation in India, thus upgrading business in India to sustainable competitiveness.

With two locations in India, CESD operates across the country and has also been active in parts of South and South East Asia, Middle East, and Africa. It has held institutional partnerships and memberships of the United Nations Global Compact, Global Reporting Initiative, International Integrated Reporting Council, Carbon Disclosure Project, development agencies of Canada, the USA, the UK, and Germany.

Delhi | Mumbai
www.sustainabledevelopment.in
/ciicesd